# Population demographics and spatial ecology of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) inhabiting coastal waters at the North West Cape, Western Australia

By

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# SUMMARY

Increasing human presence in coastal areas is threatening these important nearshore ecosystems and their associated fauna. Due to their coastal distribution and slow life history, inshore dolphins are vulnerable to anthropogenic activities associated with coastal areas. This is particularly the case in north-western Australia, a rapidly changing region with limited information on the status of the Near Threatened Indo-Pacific (IP) bottlenose dolphin (*Tursiops aduncus*) inhabiting its coastal waters. The North West Cape (NWC) in Western Australia (WA) is a diverse environment with mixed levels of protection including waters within and outside the Ningaloo Marine Park (NMP). Preliminary evidence indicated that the NWC is of importance to IP bottlenose dolphins, but information about their ecology is lacking. In this study, I used boat-based surveys, photo-identification, behavioural observations and population and species distribution modelling techniques to investigate IP bottlenose dolphin abundance, site fidelity, distribution, and habitat use. This study provides the first demographic assessment of IP bottlenose dolphins at the NWC, identifies areas of high probability of dolphin occurrence, and reveals key areas for foraging, resting, and travelling. Overall, the results from my study improve the understanding of IP bottlenose dolphin ecology and provide the basic knowledge required to enhance their conservation and management in this region.

Capture-recapture modelling and site fidelity indexes revealed that a large IP bottlenose dolphin population (311 – 370 individuals) inhabits these coastal waters (Chapter 2). The population is composed of a large proportion of dolphins that use the area occasionally (non-residents, 58%), and a smaller proportion of dolphins that use the area regularly (residents, 42%) (Chapter 2). The large number of both resident and non-resident bottlenose dolphins found throughout the coastal waters off the NWC suggest this area, as well as neighbouring waters outside my study area, are of high importance to this species.

Species distribution modelling of IP bottlenose dolphins revealed a strong preference for shallow waters (7 – 13 m deep), less than 2000 m from the coast and up to 7000 m from boat launch sites (Chapter 3). Areas of high probability of occurrence for dolphins varied seasonally but generally extended from the tip of the NWC, down the eastern side, overlapping with designated Sanctuary Zones as well as occurring in waters beyond the boundaries of the NMP (Chapter 3). The spatial distribution patterns of IP bottlenose dolphins at the NWC are likely the result of prey availability and predation risk, with dolphins likely choosing the safest and most productive waters. Distribution modelling incorporating behavioural data, in fact, revealed that coastal waters of the NWC are functionally important for resting, foraging and travelling behaviours (Chapter 4). Core areas for each behaviour were located both within the NMP and outside the current marine park boundaries. Resting schools of IP bottlenose dolphins showed a preference for shallow waters in designated Sanctuary Zones (Chapter 4). I hypothesise that IP bottlenose dolphins are selecting the most appropriate habitat to reduce the threat of predation in times of reduced vigilance and increased vulnerability. Foraging and travelling schools were more widespread throughout the study area. Foraging was more likely to occur 3000 – 5000 m from boat ramps in areas of moderate seabed slope (Chapter 4). The characteristics of the seascape (i.e. seabed slope and oceanographic conditions) at these locations likely leads to the aggregation of important prey species for IP bottlenose dolphins and are most conducive to the capture of prey. Travelling schools were more likely to occur 1000 – 2000 m from the coast and in water depths of 7 – 12 m, but as deep as 20 m (Chapter 4). These travelling areas represent important corridors between foraging and resting patches.

Findings from my study indicate that the study area, as well as adjacent waters in the wider NWC region, are of high importance to IP bottlenose dolphins, highlighting the potential vulnerability of this species to increasing and cumulative anthropogenic stressors

associated with these areas. This study provides crucial baseline information that can be incorporated by wildlife agencies into future management plans for the NWC region. Such information is crucial for informing effective conservation strategies to mitigate impacts from repeated and cumulative anthropogenic impacts in the region. Additionally, I have provided recommendations for future research directions that should advance our knowledge of IP bottlenose dolphin ecology and enhance their conservation in the wild.

# DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed:

PHaughey

Date: 01/09/2020

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# PUBLICATIONS

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**Statement of authorship**

I (R.H) am the principal contributor for each chapter. My primary supervisor, Dr. Guido J. Parra (G.J.P) is a co-author on all manuscripts derived from this thesis due to his significant input, advice and guidance in study design, data analysis, manuscript writing and editing. My secondary supervisor, Dr. Ryan Baring is a co-author on manuscripts derived from objectives 2 and 3 of this thesis due to his significant input, advice and guidance in data analysis, manuscript writing and editing. Tim Hunt (T.H) and Daniella

Hanf (D.H) are co-authors on all manuscripts derived from this thesis due to their significant contribution to data collection during 2013-2015. Robert Rankin (R.R) is a co-author on the publication that was derived from objective 1 due to his advice during the statistical analysis of that chapter. Cecilia Passadore (C.P) is a co-author on manuscripts derived from objectives 2 and 3, due to her significant help and advice whilst I was learning ArcGIS and Biomod2.

Chapter 1:

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R.H with editing and input from R.B and G.J.P

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# PERMITS

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# 1 CHAPTER 1: GENERAL INTRODUCTION

The world’s oceans cover over 60% of the earth’s surface and contain a significant proportion of the world’s biodiversity (Davidson et al., 2012). Even though the oceans occupy such a large space, increased human interaction with and exploration of the marine environment, means no area has been completely unaffected by human impacts (Davidson et al., 2012, Crain et al., 2009a, Halpern et al., 2015, Parravicini et al., 2012, Halpern et al., 2008). Coastal waters (i.e. the part of the ocean adjacent to the coast, that is considered to be part of the adjacent state or territory), are highly productive and valued ecosystems, but an increasing human population has caused these areas to become some of the most heavily used and at risk marine systems (Costanza et al., 1997, Lotze et al., 2006, Halpern et al., 2008, Worm et al., 2006, Griggs, 2017). Nearly 37% of the Earth’s seven billion people live within 100 kilometres of the coast (Sale et al., 2014). As a result, coastal ecosystems face increasing and cumulative anthropogenic pressures from overfishing, habitat degradation, pollution, urbanisation, disturbance from vessels and climate change (Halpern et al., 2008, Lotze et al., 2006, Diaz and Rosenberg, 2008, Crain et al., 2009a, Davidson et al., 2012, Sale et al., 2014, Brown and McLachlan, 2002). Consequently, the conservation of marine environments and coastal waters in particular, is greatly challenged by human presence, use and interaction (Davidson et al., 2012, Halpern et al., 2008, Parravicini et al., 2012).

A decline in the condition of coastal waters has negatively affected a number of critical ecosystem services (Worm et al., 2006). The ecosystems that provide these services (e.g. coral reefs, seagrass beds, salt marshes, mangroves, sandy beaches and dune systems) and the taxa that reside within them, are of great value to humans, providing; coastal protection, erosion control, water purification, food sources, nutrient cycling, tourism, recreation and research opportunities (Barbier et al., 2011). For example, in 2010, the world's oceans were estimated to contribute $2.1 trillion Australian dollars (with this value expected to double before 2030), to the world's economy through industries that mainly take place within coastal ecosystems (e.g. aquaculture, tourism, water transport, fisheries, port activities, maritime equipment, oil and gas, and shipbuilding and repair) (OECD, 2016). The demand to maintain these marine industries, and continue to support growing human populations in coastal areas, has led to major biodiversity declines and losses (Hoffmann, 2010, Young et al., 2016, Davidson et al., 2012, Ceballos et al., 2015, McCauley et al., 2015).

Marine megafauna (i.e. marine mammals, sea turtles, sharks and rays) that inhabit coastal waters are subject to these increasing pressures from anthropogenic activities, and therefore, are at high risk of population declines and local extinction (Davidson et al., 2012, McCauley et al., 2015, Avila et al., 2018). Marine megafauna play important roles in marine ecosystem functioning, and are socially, economically, and culturally important (Pimiento et al., 2020). Despite their ecological value, populations have experienced vast declines, and many species have experienced local extinctions during the last century. Among these species, marine mammals in particular have suffered numerous cases of population declines and species extinctions as a result of increased human pressures (Avila et al., 2018, Baylis et al., 2015, Estes et al., 2009, Harkonen et al., 2012, Hoffman et al., 2016, Pompa et al., 2011, Rojas-Bracho and Reeves, 2013). One of the best-known cases of such declines, is the Vaquita (*Phoecoena sinus*). Currently listed as Critically Endangered by the International Union for the Conservation of Nature (IUCN), and, experiencing continued and rapid decline, the species has less than 19individuals left in the wild, the result of being subjected to a long history of unsustainable bycatch (Rojas-

Bracho and Reeves, 2013, Rojas-Bracho and Taylor, 2017, Thomas et al., 2017, Jaramillo-Legorreta et al., 2019). Recent estimates report that 38 marine mammal species are considered globally Endangered or Threatened with an additional 31 considered to be Data Deficient by the IUCN. When appropriate management measures and policies are established and enforced, Marine Protected Areas (MPAs) can be effective tools for addressing threats and reducing impacts on marine mammals. However, MPAs must encompass biologically relevant areas for species, highlighting the need for robust ecological studies of populations (di Sciara et al., 2016a, Hartel et al., 2015, Hoyt, 2011). When robust baselines are established, this information can be incorporated into the planning of location and extent of MPAs, increasing the effectiveness of these areas (di Sciara et al., 2016a, Hoyt, 2011).

Scientifically informed conservation actions can improve the status of species and populations, preventing further declines and loss (Hoffmann, 2010). In the case of highly mobile marine megafauna, such as marine mammals, the design and implementation of MPAs should consider knowledge on species demography, threats the species are facing, spatially explicit information on species distribution patterns and habitat use, and an understanding of the environmental, anthropogenic and behavioural processes driving such patterns in order to maximise their chance of success (Hoyt, 2011, Hartel et al., 2015, Ashe et al., 2010, Gormley et al., 2012). In this thesis, I complete the first demographic assessment of Near Threatened Indo-Pacific (IP) bottlenose dolphins (*Tursiops aduncus*) at the North West Cape (NWC), Western Australia (WA). Additionally, I detail areas of high probability of occurrence and key areas for important biological processes (i.e. foraging, resting and travelling), greatly improving the scientific knowledge for IP bottlenose dolphins at the NWC, and more broadly, the species in general. This knowledge can now be incorporated into future spatial conservation planning and management decisions that affect this species. In this chapter, I detail the background and rationale for a study of this nature.

## 1.1 Marine Protected Areas

Currently, 5.3% of the world's oceans fall within actively managed MPAs, with 2.5% afforded high protection in the form of no-take reserves (Marine Conservation Institute, 2020). MPAs are defined as ‘a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values’ (Dudley, 2008, Day et al., 2012). Establishment of MPAs is often done to protect vulnerable species and ecosystems, conserve biodiversity, minimise the risk of species extinction, increase the productivity of fish and marine invertebrate species and allow the public to be involved with conservation, with areas often selected based on high species abundance or biodiversity (Salm et al., 2000, Hooker et al., 2011, Holt, 2009).

Growing scientific evidence indicates that when appropriately planned and managed, MPAs can be beneficial for restoring fish populations (Sala and Giakoumi, 2017, Bonaldo et al., 2017, Topor et al., 2019), increasing ecosystem functioning, resilience and stability (Roberts et al., 2017, Mellin et al., 2016, Alonso Aller et al., 2017, Topor et al., 2019), and providing multiple socio-economic benefits (Rodríguez-Rodríguez et al., 2019, Christie et al., 2015). While the establishment of MPA's may serve as effective conservation tools for threatened species, their success depends highly on robust knowledge about species distribution, abundance, and habitat use patterns, and an understanding of the environmental, anthropogenic, and biological processes driving such patterns (Salm et al., 2000, Hooker et al., 2011, Hoyt, 2011). Applying this knowledge will allow the delineation of boundaries to encompass areas that are biologically and ecologically relevant to target populations (Hooker et al., 2011, Salm et al., 2000, Hoyt, 2011). This is particularly the case for highly mobile, wide-ranging species such as marine mammals (Hooker et al., 1999, Hooker and Gerber, 2004, Wilson et al., 2004, Hartel et al., 2015, Lambert et al., 2017, Dwyer et al., 2020).

Due to the fluid nature of the marine environment, variable oceanographic conditions and limited physical boundaries, planning of MPA boundaries should account for species that exhibit large home ranges and any potential variations to these distribution ranges, movement patterns and habitat use (Berghan et al., 2010, Hooker et al., 2011, Lambert et al., 2017). Best-practice management should also develop an understanding of what happens outside protected area boundaries (i.e. dispersal of individuals and population processes) as a result of the non-static and cumulative nature of threats to marine environments (Wilson, 2016, Nykänen et al., 2018).

## 1.2 Marine megafauna – important for ecosystem functioning and biodiversity

One of the most severe problems currently faced by conservation scientists and managers is the loss of biodiversity and high extinction rates. To further prevent declines, engaging in adaptive management is crucial to maintain ecosystem structure, function and support healthy ecosystems (Estes et al., 2011, Mazzoldi et al., 2019, Pimiento et al., 2020, Hammerschlag et al., 2019, Estes et al., 2016b, Ceballos et al., 2015, McCauley et al., 2015). Marine apex predators, such as marine mammals, have been identified as serving key ecological roles, with their presence often used as a potential signal of ecosystem health and their functional traits linked to nutrient storage and cycling, community shaping and habitat provision (Bossart, 2011, Moore, 2008, Pimiento et al., 2020, Hammerschlag et al., 2019, Tavares et al., 2019, Estes et al., 2016b, Kiszka et al., 2015, Heithaus et al., 2008). For example, in the deep ocean, whales and other marine mammals consume nutrients and then later transfer them to the surface through feces and physical mixing, allowing them to be up taken by other species (Roman and McCarthy, 2010). This process has been estimated to have been reduced by 80% as a result of marine mammal declines (Doughty et al., 2016). Albeit a smaller species of megafauna, the sea otter (*Enhydra lutris*) plays a pivotal role in the functioning of kelp forest ecosystems in the North Pacific Ocean, predating on sea urchins and maintaining kelp density (Estes et al., 2016a). In this region, kelp was considered the primary food source for Steller’s sea cow (*Hydrodamalis gigas)* (Estes et al., 2016a). A human induced population decline of sea otters about 20 years ago, led to 100% increase in sea urchin density and a resultant 10-fold decline in kelp density (Estes et al., 2016a). Although the kelp forest collapse preceded the extinction of the sea cow in this region, it has been hypothesised that a greatly reduced food source was a contributing factor to this extinction (Estes et al., 2016a). Additionally, marine megafauna species are generally considered to be charismatic (i.e. species that have "the ability to capture the imagination of the public and induce people to support conservation action and/or to donate funds"; Walpole and Leader-Williams, 2002, Mazzoldi et al., 2019). As a result, these species have the potential to raise public awareness and promote conservation actions whilst also stimulating economies, with human desire to observe these species in their natural environments, contributing to the growth of marine tourism (Mazzoldi et al., 2019). Despite their recognised ecological, social and economic values, baseline data on the ecology of a large proportion of the world's marine megafauna is lacking, hampering the development of effective conservation and management strategies (Estes et al., 2016b).

## 1.3 Dolphins in coastal waters

Globally, conservation of cetaceans is challenged by a lack of basic information on species distribution and abundance, with less than 50% of the ocean's surface surveyed for cetaceans, and one third of marine mammal species (including cetaceans) assigned an unknown conservation status (Braulik et al., 2018, Kaschner et al., 2012). Lack of baseline data means that cetaceans are sometimes excluded or given limited attention in environmental impact assessments, marine conservation planning, coastal zone management or during identification of MPAs (Braulik et al., 2018).

Among cetaceans, dolphins fill a broad range of ecological niches, occurring in all oceans from polar to tropical regions, in both coastal and oceanic waters (Estes et al., 2016b, Kiszka et al., 2015). Distribution of coastal dolphins heavily overlaps with areas of industrialisation, coastal development, fisheries, and boat traffic. This exposes them to a range of threats from increased human presence including climate change, bycatch, marine litter ingestion and entanglement, ship strikes, chemical and noise pollution, and competition with commercial and recreational fishers for food (Williams, 2014, Bejder et al., 2006, Stensland and Berggren, 2007, Amir, 2010, Shirakihara and Shirakihara, 2012, Lane et al., 2014, Fossi et al., 2018). Many of the threats faced by coastal dolphins can result in; displacement from core habitats, disturbance of critical behaviours, increase in fishing interactions, depletion of prey and an increase in competition, vessel strikes and a decrease in health (Lusseau and Higham, 2004, Bejder et al., 2006, Chabanne et al., 2012, Hawkins et al., 2017). In addition to their home ranges overlapping with multiple threats, the life history of coastal dolphins (i.e. long lived, slow to sexually mature and producing highly dependent offspring) makes them highly susceptible to population declines (Smith et al., 2016, Hawkins et al., 2017).

To predict the consequences of environmental change and reduce the effects of increasing human pressure on coastal dolphin species, we need to have an educated understanding about the ecology, behaviour and life history traits of the species in question for effective conservation and management (Berger-Tal et al., 2011, Kiszka et al., 2015). Despite many coastal dolphin populations displaying moderate to high levels of site fidelity and occupying relatively small home ranges, dolphins are wide ranging and often undergo significant movements between distinct geographical areas for foraging, reproduction and other behaviours across various life stages (Lascelles et al., 2014). Coastal dolphins tend to aggregate in places where food resources are plentiful and where they can reproduce and nurture their offspring, however due to their transitory movements it is often impossible to encompass a population's entire year-round distribution, meaning complete protection is challenging (di Sciara et al., 2016a, Holt, 2009, Hooker et al., 2011). Additional challenges arise when studying dolphins due to their highly mobile nature and life history, which enables them to spend extended periods of time submerged below the surface of the ocean (Braulik et al., 2018). The difficulty associated with studying species of this nature has resulted in a paucity of knowledge and lack of information on the demography and ecology of many species (Marcer et al., 2013, Braulik et al., 2018). Compiling robust baseline data for populations and the threats they face has been identified as a critical first step in identifying priority species and locations that urgently require conservation efforts (Braulik et al., 2018). Effective management of coastal dolphins should be guided by; the location and timing of importance for key areas, variables that influence presence and threats that may impact species and their habitats (Lascelles et al., 2014, Bearzi, 2012).

## 1.4 Coastal dolphins in Australia

Australia has three recognised tropical coastal dolphin species, the Australian humpback dolphin (*Sousa sahulensis*), the Australian snubfin dolphin (*Orcaella heinsohni*) and the IP bottlenose dolphin. Australian humpback dolphins are thought to be widely distributed along the northern Australian coast from approximately the Queensland-New South Wales border to Shark Bay, Western Australia (Parra et al., 2017a, Figure 1.1). Australian snubfin dolphins have been reported from Exmouth Gulf, Western Australia across the northern coastline and south along the east coast to Brisbane, Queensland (Parra et al., 2017b, Figure 1.1). Indo Pacific bottlenose dolphins have been observed in both tropical and temperate waters along the Australian coastline (see section 1.6 for further discussion on IP bottlenose distribution). Globally, Australian humpback and snubfin dolphins are listed as Vulnerable, and IP bottlenose dolphins as Near Threatened under the IUCN Red List of Threatened Species (Parra et al., 2017b, Parra et al., 2017a, Braulik et al., 2019). Nationally, all three species are listed as 'cetacean' under the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 and as such, are all considered to be Matters of National Environmental Significance (MNES) (DoE., 2013, Miller et al., 2018, EPBC Act., 1999). The Action Plan for Australian Mammals assessed Australian humpback and snubfin dolphins as Near Threatened, whilst IP bottlenose dolphins are considered Data Deficient (Ross, 2006, Woinarski et al., 2014).

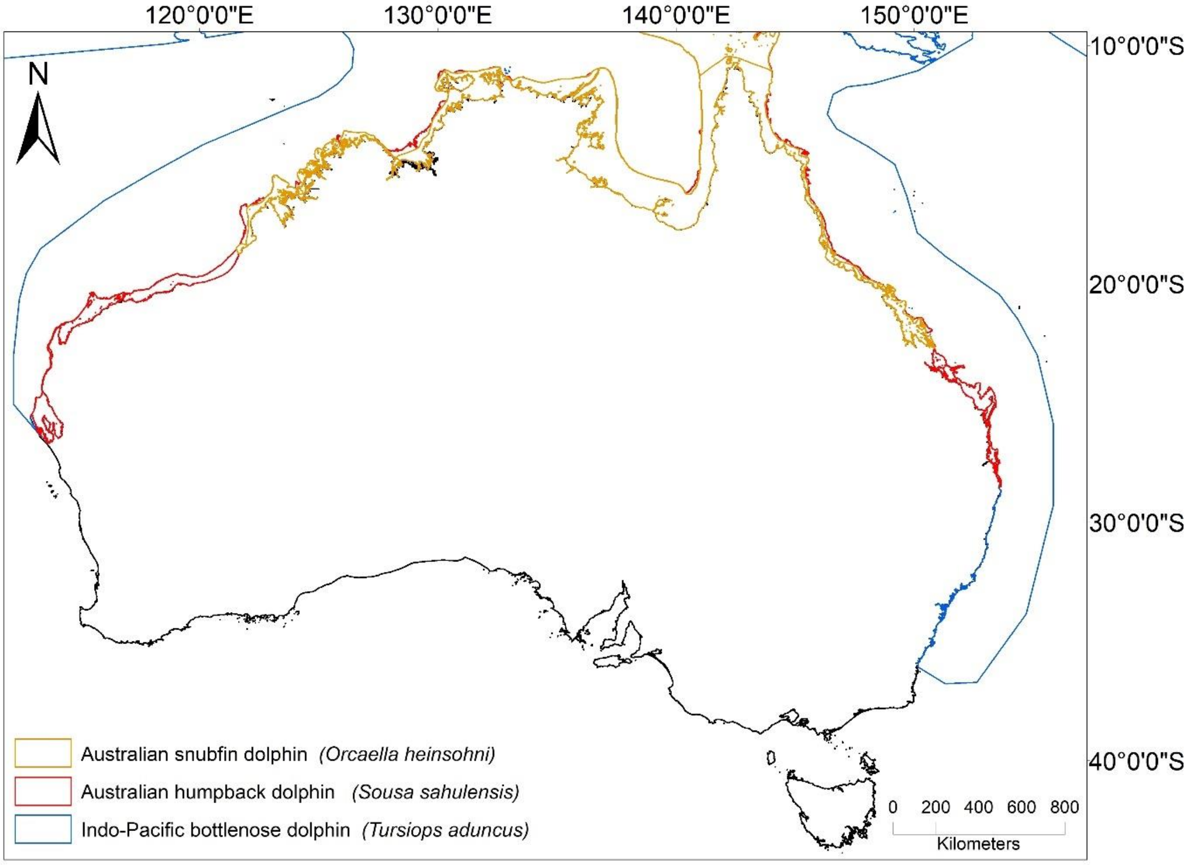


**Figure 1.1:** The inferred distribution of Australia's three tropical inshore dolphins; the Australian snubfin, Australian humpback and Indo-Pacific bottlenose dolphin

Australia’s dolphins are protected internationally under the IUCN treaty, and nationally under the EPBC Act 1999 (Miller et al., 2018, EPBC Act., 1999). In Australia, it is illegal for dolphins to be killed, harmed or interfered with, and any proposed actions that are likely to have detrimental impacts are required to be assessed and approved by the Federal Minister for the Environment (DoE., 2013). However, baseline ecological data on Australia’s dolphin species is lacking throughout most of their ranges, preventing robust impact assessments in some locations. In recognition of the urgency and need for such information, the Federal Australian Government developed a national research framework detailing knowledge gaps and research priorities to inform the conservation and management of Australia’s tropical inshore dolphin species (DoE, 2015). Among the key research priorities is to conduct dedicated long-term (multi-year) studies at appropriate key-strategic sites (i.e. most ecologically significant) on dolphin distribution, abundance, and habitat use. The NWC in north-western Australia was identified as a key site for inshore dolphin research, given that it is an area likely to be subjected to further coastal development in the future.

Whilst studies of IP bottlenose dolphin populations across Australia have contributed to some knowledge gaps on population demographics (e.g. Möller et al., 2002, Ansmann et al., 2008, Fury and Harrison, 2008, Nicholson et al., 2012, Sprogis et al., 2016a), habitat use and ranging patterns (e.g. Heithaus and Dill, 2002, Heithaus and Dill, 2006, Ansmann et al., 2015a, Sprogis et al., 2018a, Sprogis et al., 2016b), morphology (van Aswegen et al., 2019), social structure and cultural transmission of tool use (e.g. Randić et al., 2012, Frère et al., 2010, Kopps et al., 2014, Krützen et al., 2014), populations across most of north-western Australia and in particular around the NWC are still largely unknown (Figure 1.2). Despite the Australian Government recognising this area as a key site for inshore dolphin research, baseline data is still missing for coastal dolphin populations in the region (Allen et al., 2012, Bejder et al., 2012, Hanf et al., 2016).

## 1.5 North Western Australia and the North West Cape: a rapidly changing region with mixed levels of protection inhabited by coastal dolphins

Economically, Australia’s oceans generate billions of dollars through the industries of water transport, marine tourism, infrastructure, oil and gas exploration and extraction, and fishing and aquaculture ($71.5 billion AUD in 2013-2014 and $68.1 billion AUD in 2015-2016) (AIMS., 2018). Western Australia (WA) is no exception, having utilised resource extraction for many years, with the first resource extraction industry dating back to the gold rush in the 1980s (Bolton, 2008). Also, WA is Australia’s fastest growing state fuelled by oil and gas mining industries which have experienced surges in growth over the last 20 years (Clements et al., 1996, DPMC, 2015, Hanf et al., 2016). The Gascoyne region which encompasses the NWC (Figure 1.2) is home to both marine and terrestrial species that attract domestic and international interest, creating a high demand for both water and land based recreational activities (Gascoyne Development Commission. et al., 2013) Additionally significant oil and gas activities operate in waters off the coast of this region (SGS Economics and Planning., 2011). The Gascoyne region’s gross regional product continues to grow annually, with significant contributions from the tourism, retail, agriculture, fishing and mining sectors and an estimated gross regional product of $1740 million AUD by 2050 (SGS Economics and Planning., 2011, Gascoyne Development Commission., 2015) The Pilbara region, which borders the eastern side of Exmouth Gulf (Figure 1.2), has been estimated to produce more money than the individual economies of 119 countries (DPMC, 2015). Although the development boom appears to be slowing, coastal north-western Australia is likely to remain an area of high anthropogenic activity, with the

Australian Government prioritising northern Australia for future growth in energy export, local human populations and tourist visitation (DPMC, 2015, Hanf et al., 2016, Gascoyne Development Commission. et al., 2013, Gascoyne Development Commission., 2015).

The NWC is located  approximately halfway up the west coast of Australia (21.8 degrees South and 114.1 degrees East) and covers the northern part of the Ningaloo Reef; the largest fringing reef in Australia (CALM and MPRA, 2005) (Figure 1.2).

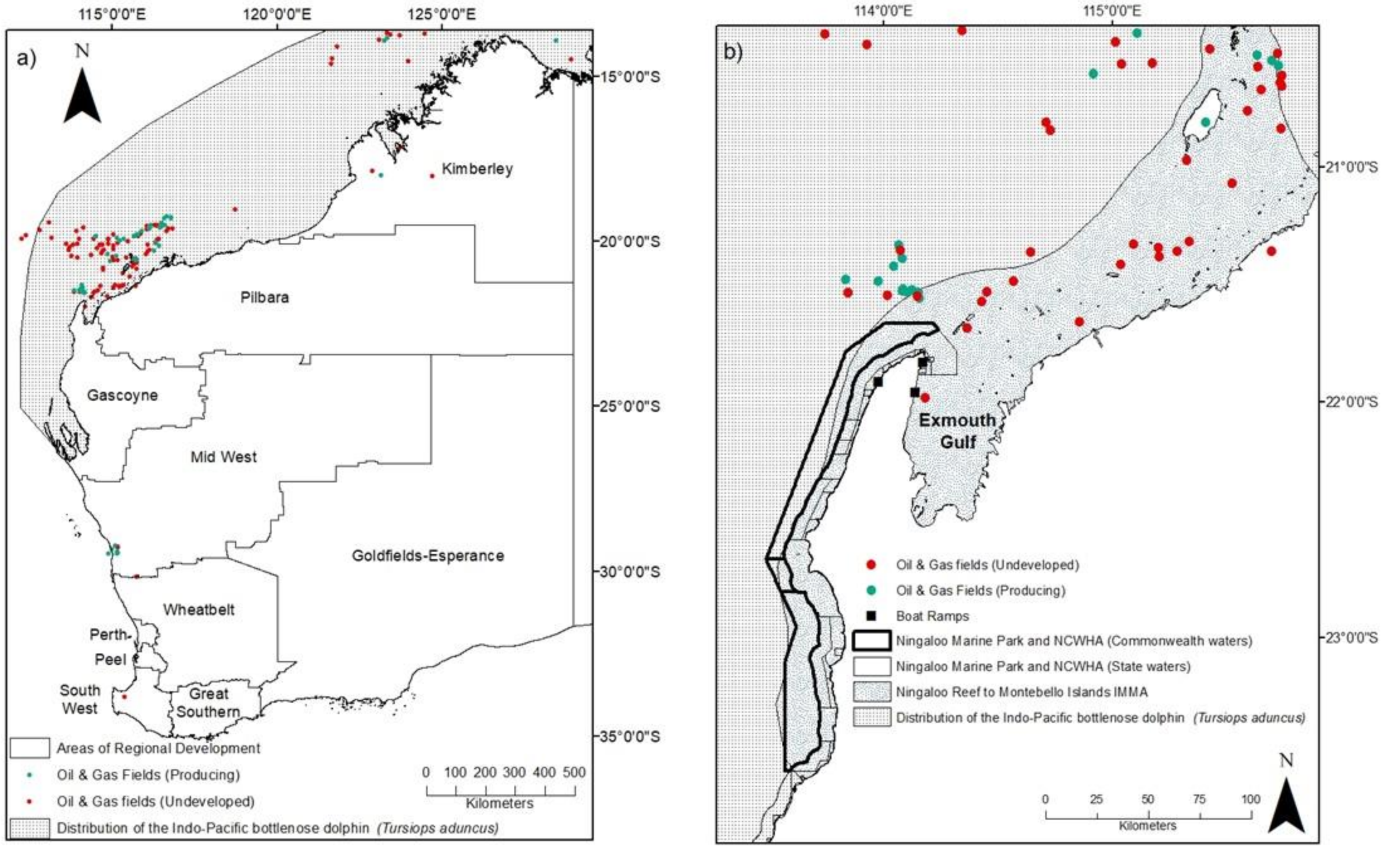


**Figure 1.2:** a) Map of Western Australia showing the inferred distribution of Indo-Pacific bottlenose dolphins, the location of producing and undeveloped oil and gas fields, the boundaries of Western Australia's areas of regional development and the location of the North West Cape (in box). b) Map of the North West Cape showing the distribution of Indo-Pacific bottlenose dolphins, boat ramp locations, oil and gas fields, the boundaries of the State and Commonwealth Ningaloo Marine Parks and the marine component of the Ningaloo Coast World Heritage Area (NCWHA) and the Ningaloo Reef to the Montebello Islands Important Marine Mammal Area (IMMA) (IUCN-MMPATF, 2020).

Hundreds of oil and gas structures are currently located offshore from the NWC, at the north-west Australian continental shelf (Figure 1.2), which will likely require decommissioning in the next decade, with further structures likely to be added (Pradella et al., 2014, DoISER., 2019). In addition to oil, gas and mineral industries operating in adjacent waters, the NWC supports WA’s second largest prawn trawl fishery, which operates in the Exmouth Gulf (Kangs et al., 2006, Pitcher et al., 2016).

The coastal waters of the NWC have different levels of statutory protection, with waters to the west and north of the NWC within the Ningaloo Coast World Heritage Area (NCWHA) and the Ningaloo Marine Park (NMP; Commonwealth and State Waters) (Figure 1.2). The NMP was originally gazetted in 1987 after the conservation significance of the Ningaloo Reef was realised (CALM and MPRA, 2005). In 2004, the boundary was then extended to cover the entire fringing reef system, still excluding the majority of the Exmouth Gulf system (CALM and MPRA, 2005). Australia’s World Heritage properties and marine parks are provided with a high level of protection between three levels of Government (National, State, and Municipal), community, indigenous custodians and the Ningaloo Coast World Heritage Advisory Committee, working together to manage and maintain the World Heritage values of the area (DoEWHA, 2010). The most recent management plan for the NMP (Management Plan 52; 2005-2015) had a vision for the flora, fauna, habitats, sediment and water quality to be in the same or better condition in 2015 than they were in 2005 by maintaining the marine biodiversity and ecological processes of the marine park (CALM and MPRA, 2005). To achieve this the NMP is managed with a zoned ecosystem-based management approach under a cooperative agreement with the above mentioned parties (DoEH, 2002, DoEWHA, 2010, CALM and MPRA, 2005). Within the boundaries of the NMP, only approved commercial and recreational activities that are consistent with the conservation values of the park are permitted (CALM and MPRA, 2005). Despite being recognised as an important ecosystem and receiving nomination for spatial management, the Exmouth Gulf lacks formal protection and is not included in neither the NMP nor the NCWHA.(CALM and MPRA, 2005, DoEH, 2002, DoEWHA, 2010).

The NMP and NCWHA are renowned for their wealth of ecological values, particularly that of high biodiversity and associated abundance of marine fauna (CALM and MPRA, 2005). Managers of the NMP and the NCWHA perceive coastal dolphins to be of high conservation significance to the Ningaloo Coast ecosystem and recognise their intrinsic ecological value through their contribution to the biodiversity and ecological processes within this region (CALM and MPRA, 2005, DoEWHA, 2010). At the time the NMP and NCWHA management plan was written there was lack of ecological knowledge on dolphin populations and the impacts of identified threats within the marine park. As a result, management actions were focused on the development of a code of conduct to enable management of any increase in tourist interaction (high priority), research to increase the understanding of the importance of the area to dolphin populations (medium priority), understanding the impacts of nature-based tourism on cetacean behaviour (medium priority) and maintaining records of entanglements and strandings (low priority) (CALM and MPRA, 2005). The long term target from the above management actions was for no loss of diversity as a result of human activity within the Ningaloo Marine Park.

Recently in a global conservation initiative for marine mammals, the NWC was recognised to be important to marine mammals and was included in a large Important Marine Mammal Area (IMMA) spanning from the Ningaloo Reef further north to the Montebello Islands (Figure 1.2). IMMAs highlight habitat that has the potential to be delineated and managed, placing merit in place-based monitoring and protection, aiming to improve the conservation of marine mammal species or populations inhabiting these areas (Corrigan et al., 2014, Marine Mammal Protected Areas Task Force., 2016-2020).

Aerial surveys targeting other species and boat-based surveys have confirmed the presence of inshore dolphins in this area and have found that IP bottlenose dolphins are common in these waters (Preen et al., 1997, Allen et al., 2012). However, there is still limited information available on their ecology, and the conservation status of IP bottlenose dolphins in this region. This lack of knowledge hinders the management and conservation of this Near Threatened species (Allen et al., 2012, Bejder et al., 2012). With recent industrial booms and port development in Queensland, Australia, contributing to declines in population size and range of coastal dolphins (Cagnazzi et al., 2020, Cagnazzi et al., 2013b), the importance of using evidence-based scientific knowledge to effectively manage populations in other areas of increasing development, is a critical next step to prevent further declines.

Species distribution modelling of IP bottlenose dolphins using data collected opportunistically during aerial surveys for dugongs, indicated the Exmouth Gulf and waters to the north-east of the NWC were likely to be important for lP bottlenose dolphins (Hanf, 2015). Prior to the commencement of this study, no analysis on IP bottlenose dolphin population demographics had been completed in this region. Data collection for this study commenced in 2013 in conjunction with a study on Australian humpback dolphins at the NWC (Hunt, 2018) and was continued over 2018 and 2019.

## 1.6 The Indo-Pacific bottlenose dolphin (*Tursiops aduncus*): current knowledge and information gaps

The IP bottlenose dolphin (Figure 1.3) was taxonomically recognised as a separate species to the Common bottlenose dolphin (*Tursiops truncatus)* in 2000 after much debate and uncertainty (Wang et al., 1999, Wang et al., 2000a, Wang et al., 2000b). Due to the taxonomic uncertainty of this species, many early studies made no distinction between *T. truncatus* and *T. aduncus*, confusing the knowledge that exists for both species (Wang and Chu Yang, 2009).

IP bottlenose dolphins, like most marine mammals, are K-strategists, with long life expectancy (i.e. 40 years), few offspring (i.e. single calf every two to three years), long gestation (i.e. about 12 months), long parental care (i.e. 18 to 24 months), and late sexual maturity (i.e. females 12 to 15 years and males 10 to 15 years) (Wang and Chu Yang, 2009, Mann et al., 2000).

Figure 1.3: **A mother-calf pair of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the North West Cape, Western Australia.**

Currently, for the IP bottlenose dolphins, there are many gaps in our understanding of the global distribution and abundance, ecology, behaviour and physiology, life history and outcomes of anthropogenic disturbance, as well as further taxonomic uncertainty. So far, IP bottlenose dolphins have been recorded in the Indian and western Pacific Oceans, with populations also observed in cooler temperate waters (Wang and Chu Yang, 2009). The distribution of IP bottlenose dolphins is thought to extend throughout the coastal waters of the oceans from the Solomon Islands and New Caledonia to the southern tip of South Africa, central Japan and along the Australian coastline (Wang and Chu Yang, 2009). The level of continuity of distribution within this range is unknown, with multiple localised populations appearing to be isolated from each other (Wang and Chu Yang, 2009). Throughout those regions, IP bottlenose dolphins have been commonly observed in multiple habitats including; rocky and coral reefs, over sandy bottoms and seagrass beds, and in near shore continental shelf areas of water depths less than 100 m deep (Inoue et al., 2017, Vargas-Fonesca et al., 2018, Heithaus and Dill, 2002, Wang and Chu Yang, 2009, Sprogis et al., 2018a).

In 2008, the IUCN listed IP bottlenose dolphins as Data Deficient, meaning not enough information was known about the species to assign them a conservation status (Hammond et al., 2012). The IUCN review highlighted the need for further research into population sizes, distribution, life history and ecology of the species (Hammond et al., 2012). In 2019, the IP bottlenose dolphin was reviewed again by the IUCN and assigned a Near Threatened status (Braulik et al., 2019). This conservation status does not recognise the species to be currently threatened but recognises that it is close to qualifying, or likely to qualify, for a threatened category in the near future. For the IP bottlenose dolphins, there are still many knowledge gaps with information on distribution, abundance, habitat use and population trends still limited.

## 1.7 Anthropogenic impacts and threats faced by Indo-Pacific bottlenose dolphins at the North West Cape

Within north-western Australia, potential threats for IP bottlenose dolphins include; bycatch, entanglement, habitat modification and loss, competition for food with fishers, pollution, climate change and disturbance from boats (Ross, 2006, Robbins et al., 2017). The NWC is a popular destination for recreational and commercial fishing, marine ecotourism and mineral extraction operates in neighbouring waters. Exmouth, the township connected to the NWC, received an average of 139,700 and 153,000 annual visitors for the 2015-2017 and 2017-2019 periods, respectively, with numbers expected to increase in the future (Tourism of WA., 2020, Tourism of WA., 2019). The NMP, a major source of visitation to the area, is a multi-use marine park managed by a zoning scheme, prohibiting extractive activities (i.e. fishing) in some areas of the park, but predominantly allowing recreational fishing throughout most of the park (CALM and MPRA, 2005). Also, the Exmouth Gulf, outside the boundaries of the NMP, receives no formal protection and supports Western Australia's (WA) second largest prawn trawl fishery (Kangs et al., 2006).

### *1.7.1 Vessels (disturbance, displacement and boat strike)*

Due to the substantial overlap of inferred distribution with human-populated coastal environments, IP bottlenose dolphins are exposed to increasing impacts from repeated long-term exposure to vessel traffic, such as displacement, behavioural changes and boat strike (Ross, 2006, Bejder et al., 2006, Nowacek et al., 2007, Marley et al., 2017, Schoeman et al., 2020). Displacement and behavioural changes in dolphin species as a result of this overlap have been reported in numerous bottlenose dolphin *(Tursiops spp.)* populations around the world (Marley et al., 2017, Nowacek et al., 2007, Buckstaff, 2004, Jensen et al., 2009, La Manna et al., 2013, Stensland and Berggren, 2007, Lemon et al., 2006, Lusseau, 2005, Lusseau, 2003, Nowacek et al., 2001, Steckenreuter et al., 2012b). Boat strike has been recognised as a significant source of anthropogenic mortality or traumatic injury for dolphins resulting from a forceful impact between any part of a vessel (most commonly the bow or propeller) and a live animal (Van Waerebeek et al., 2007). If not immediately fatal, dolphin strikes can produce significant injuries which may temporarily or permanently hinder individuals through mutilated appendages or deep, painful wounds in muscle tissue, with high risk of infection that can take significant time to fully heal or contribute to slow, painful deaths (Dwyer et al., 2014, Byard et al., 2012, Bloom and Jager, 1994). Whilst increased vessel presence, high vessel speeds and human inattention are key determinants of vessel strike, the age, condition, behaviour and location of dolphin species are all likely contributing factors to the risk of vessel strike (Martinez and Stockin, 2013, Vanderlaan and Taggart, 2007, Parks et al., 2012, Wells and Scott, 1997). Also, younger individuals with limited swimming and diving capabilities, individuals spending more time at the surface or in shallow waters or engaged in behaviours of reduced vigilance or erratic surfacing behaviour (i.e. resting and foraging), are most at risk of vessel strike (Parks et al., 2012, Wells and Scott, 1997, Vanderlaan and Taggart, 2007, Martinez and Stockin, 2013).

As vessels become more widespread in coastal marine environments, they have the potential to significantly contribute to ambient noise in the marine seascape, occupying the same acoustic frequencies used by dolphins, potentially masking biologically important acoustic signals required for population success (Haviland-Howell et al., 2007, Jensen et al., 2009, Pine et al., 2016, Schoeman et al., 2020). At present, the Exmouth Gulf is mainly dominated by biological sounds, with low levels of noise from anthropogenic activities (Bejder et al., 2019), however a recent acoustic study at the NWC determined that vessel noise is likely to be a significant driver of behavioural disturbance in humpback whales (*Megaptera novaeangliae*) at the NWC if not managed appropriately (Sprogis et al., 2020). Vessel noise may also drive disturbance in other species that are sensitive to acoustic signals that also inhabit waters at the NWC, such as IP bottlenose dolphins. In New South Wales, Australia, Steckenreuter et al. (2012b) reported IP bottlenose dolphins avoiding commercial boats and decreasing the time spent engaged in important population behaviours, or not partaking in certain activities if boats were present (i.e. feeding and socialising and resting). As the number of boats increased and distance from the dolphins decreased, disturbance increased (Steckenreuter et al., 2012b). Also, in the Port Adelaide River-Barker Inlet Estuary, Australia, increased behavioural stress of IP bottlenose dolphins has been observed in the presence of motorised vessels (Seuront and Cribb, 2011)**.**

### *1.7.2 Interactions with fishers and fishing equipment (recreational and commercial)*

Distribution of dolphins and fishers alike are determined by the availability of fish, therefore often there is considerable spatial overlap between fishing vessels and dolphin populations (Jaiteh et al., 2012, Milmann et al., 2016, Breen et al., 2016, Zollett and Read, 2006, Goetz et al., 2014). Worldwide, bottlenose dolphins (*Tursiops sp*.) have been reported interacting with fishers, to feed on catch or discarded fish (Goetz et al., 2014, Rechimont et al., 2018, Jaiteh et al., 2012). Additionally, humans choosing to deliberately engage in food provisioning can alter the natural behaviour of dolphins by encouraging adverse behaviour, such as begging, and can affect the reproductive success and viability of populations and increase the risk of boat strike and entanglement of individuals (Senigaglia et al., 2019, Foroughirad and Mann, 2013, Christiansen et al., 2016, Donaldson et al., 2010).

The NWC is highly regarded as one of the best recreational fishing areas in Australia, with the coastal waters of the NWC containing a rich biodiversity of teleost fish species including 550 species recorded along the Ningaloo Coast and more than 780 species in the Exmouth Gulf (Mitchell et al., 2018, Williamson et al., 2006, Sumner et al., 2002, McLean et al., 2016, Fitzpatrick et al., 2019). In a study by Smallwood and Beckley (2012), shore and boat-based recreational fishing was found to occur widely throughout the NMP, with at least 16 -17% of vessels involved in recreational line fishing (~30% of vessel activities unidentified) and 9% line fishing from the shore.

Additionally, waters of the Exmouth Gulf support WA’s second largest prawn trawl fishery (Kangas et al., 2015, Kangas et al., 2007, Kangs et al., 2006). This fishery operates over 30% of the Gulf, trawling outside of the study area in the central and eastern sections of the Gulf from April to August, and in the northern sections from August to September (Kangas et al., 2015), where baseline information of IP bottlenose dolphins is still missing. The Pilbara Trawl Fishery located in waters to the north west of the NWC (north of 21º44'S), have observed bottlenose dolphins foraging in trawl nets and a bycatch rate of 12.6 dolphins per 1000 trawls (Jaiteh et al., 2012, Allen et al., 2014). Such dolphin and fishing interactions raise concerns over the potential impacts that the Exmouth Gulf Prawn Trawl Fishery may have on the IP bottlenose dolphin population over the long-term (e.g. years). The longer-term impacts to dolphin welfare may be through depletion of a food source and risk of entanglement; with some photo-identified individuals exhibiting injuries and scarring that resemble entanglement in fishing line (personal observation).

### 1.7.3 Increased development and exploration in adjacent waters

To date, coastal development in this region has preceded the collection and analysis of adequate baseline ecological information on IP bottlenose dolphins. The coastal development in the region of north-western Australia to support Australia’s resource industry (mining, gas and petroleum) has been massive, causing large-scale habitat modification and threatening coastal dolphins, with future development projects planned in coming years (Bejder et al., 2012).

Currently proposed for the immediate NWC coastal area is an oil and gas pipe assembly plant and launch site (Subsea 7 Learmonth Bundle Site) (360 Environmental, 2017). This project involves constructing a pipeline bundle fabrication facility approximately 30 km south of the town of Exmouth (outside the survey area of this study), to manufacture and subsequently tow pipelines through the Exmouth Gulf and NMP to already established offshore gas fields (360 Environmental, 2017). In the Marine Fauna Management Plan, IP bottlenose dolphins were only mentioned in an Appendix (360 Environmental, 2017). The dredging, construction and tow phases are all likely to generate high levels of noise and contribute to habitat degradation, having the potential to disturb and displace IP bottlenose dolphin individuals and likely having detrimental effects on this Near Threatened species. Environmental Impact Assessments (EIA) for this project are still ongoing, with Non-Government Organisations (NGOs) and the local community expressing numerous concerns about the approval of such a project (Smithers, 2019). This thesis forms a baseline to which future EIAs in the NWC region can refer in order to appropriately consider all threats and potential cumulative impacts for IP bottlenose dolphins in this region.

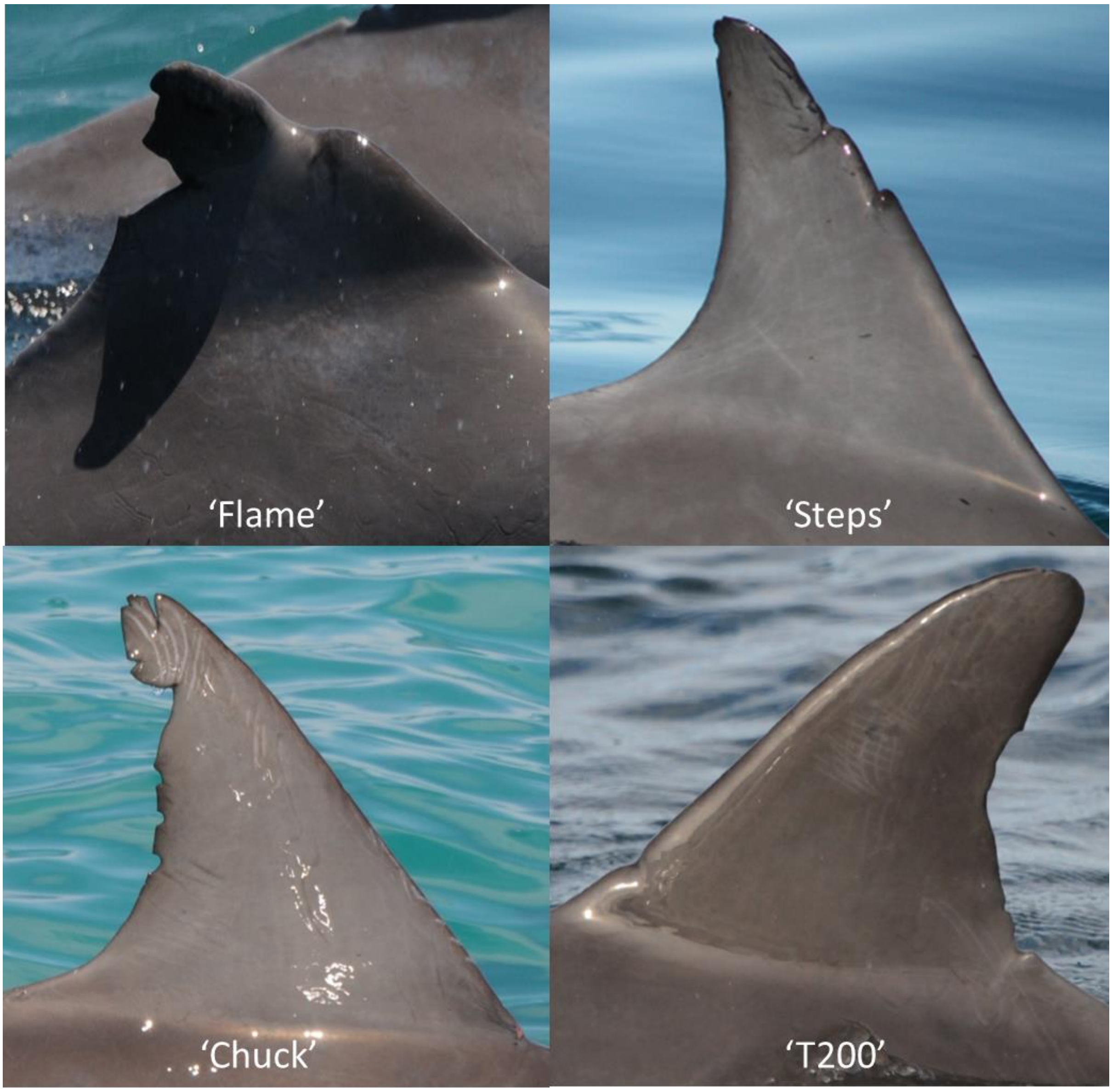
## 1.8 Research aims, objectives and thesis structure

The overall aim of my thesis was to establish baseline ecological information on the IP bottlenose dolphins at the NWC of north-western Australia to improve the scientific basis behind their conservation and management. To achieve this aim, my study had three specific objectives each related to a separate data chapter in my thesis. The specific objectives of the project were to:

1. Estimate population demographic parameters (i.e. abundance, survival and site fidelity) of IP bottlenose dolphins of the NWC (Chapter 2).
2. Investigate the spatio-temporal distribution of IP bottlenose dolphins to identify habitat preferences and areas of high probability of occurrence around the NWC (Chapter 3).
3. Investigate the behavioural processes underlying habitat selection of IP bottlenose dolphins at the NWC (Chapter 4).

Understanding the abundance, site fidelity, spatial distribution and intrinsic population processes that influence how animal populations select preferred habitat, is a critical first step for effective conservation and management. Establishing baseline information detailing the importance of the area to IP bottlenose dolphins through the study objectives will allow managers of the NMP, NCWHA and NWC to make informed conservation decisions based on scientific knowledge. Such knowledge will also provide a way forward for monitoring ongoing IP bottlenose dolphin abundance and distribution patterns to quantify if this species is experiencing declines in abundance or range within this region. This thesis is composed of five chapters. Chapter 1 discusses the background, rationale and significance of this study, and the study aims and objectives. Each data chapter (Chapters 2, 3 and 4) has been prepared as a stand-alone manuscript to be published in a peer-reviewed scientific journal. As such, some parts of the methodology overlap between the three data chapters. Chapter 2 is published (Haughey et al., 2020, Frontiers in Marine Science), while, Chapter 3 is in preparation for submission to a Frontiers in Marine Science special issue on conservation of inshore cetaceans. Chapter 4 is also being prepared to be submitted for publication in the near future. Chapter 5 contains the general discussion, conclusions and future research directions associated with this study. Tables and figures are integrated in the text of each relevant chapter. A single reference list for the entire thesis is located at the end of the thesis. Supplementary Material for each of the chapters can be found in the appendices located at the end of the thesis, where each Appendix corresponds to each data chapter.

# 2 CHAPTER 2: PHOTOGRAPHIC CAPTURE-RECAPTURE ANALYSIS REVEALS A LARGE POPULATION OF INDO-PACIFIC BOTTLENOSE DOLPHINS (*TURSIOPS ADUNCUS*) WITH LOW SITE FIDELITY OFF THE NORTH WEST CAPE, WESTERN AUSTRALIA



## 2.1 Abstract

Little is known about the ecology of Indo-Pacific (IP) bottlenose dolphins (*Tursiops aduncus*) inhabiting the coastal waters of tropical north-western Australia. In this study, I used photo-identification data collected between 2013 and 2015, site fidelity indexes and capture-recapture models to estimate the abundance and site fidelity patterns of IP bottlenose dolphins inhabiting the coastal waters off the North West Cape (NWC), Western Australia (WA). A standardized site fidelity index (SSFI) indicated low site fidelity (SSFI = 0.019) at the population level to the 130 km$^2$ study area. Agglomerative hierarchical clustering (AHC) of individual re-sight rates classified 58% of individuals as non-residents. Open POPAN modelling estimated a super-population size of 311 (95% CI: 249–373) individuals over the study period. A maximum likelihood transient model which considers both resident and non-resident individuals in a population, estimated a resident population of 141 (95% CI: 121–161) individuals and a super-population of 370 (95% CI: 333–407) individuals. These models indicate that a large population of IP bottlenose dolphins of relatively high density (an average of 2.4–2.8 bottlenose dolphins per km$^2$) inhabits the waters off the NWC. The large number of both resident and non-resident bottlenose dolphins found throughout the coastal waters off the NWC suggest this area, as well as neighbouring waters outside the study area, are of high importance to this species.

## 2.2 Introduction

The abundance and density of individuals in a population are among the most commonly used predictors of extinction risk and the conservation status of the world's land and marine mammals (Cardillo et al., 2005, Davidson et al., 2009, Lotze et al., 2017). Consequently, conservation and management decisions with the intention of protecting wildlife require a robust estimation of population demographic parameters and site fidelity patterns (Williams et al., 2002, Krebs, 2015). These demographic attributes are variable within and between species and are influenced by the survival, rate of movement, and the site fidelity (i.e., tendency to return to a previously occupied place) patterns of individuals (Lebreton et al., 1992, Switzer, 1993).

Estimating demographic parameters of species that are highly mobile and wide ranging can be difficult due to varying detection probability, unequal sampling effort, and non-random movement patterns (Thompson et al., 1998, Williams et al., 2002). Due to varying levels of individual site fidelity within a population, there is the potential to capture individuals that do not frequently occur in the study area and are often only present for short periods of time, often termed "transients" or "non-residents" (Hines et al., 2003, Clavel et al., 2008). Estimating demographic parameters of populations can be difficult when there is considerable spatial overlap of resident and non-resident individuals (Conn et al., 2011). Failure to account for the non-resident individuals can lead to biased, incorrect estimates of survival and abundance. Therefore, it is important to be aware of both "non-residents" and "residents" (Conn et al., 2011). Population demographic estimates which ignore the presence of non-resident individuals can lead to misleading estimates, incorrect interpretations about ecological relationships (e.g., predator–prey dynamics, species-habitat relationships), flawed impact assessments, and inappropriate implementation of conservation actions and resources, which would all be detrimental for populations and species that are vulnerable to human activities (Schaub et al., 2007, Clavel et al., 2008).

Marine mammals are often exposed to cumulative anthropogenic pressures because of increasing human interaction within their habitats, which creates challenges for their conservation (Maxwell et al., 2013, Avila et al., 2018). Coastal dolphins in particular, face a variety of threats including habitat loss and degradation (Jefferson et al., 2009, Cagnazzi et al., 2013b, Karczmarski et al., 2017), exposure to environmental contaminants (Storelli and Marcotrigiano, 2000, Balmer et al., 2011, Cagnazzi et al., 2013a), boat strikes (Wells and Scott, 1997, Ross, 2006, Dwyer et al., 2014), net entanglement (Jones, 1995, Bannister et al., 1996, Shaughnessy et al., 2003), and noise disturbance (Dolman et al., 2003, Buckstaff, 2004, Bejder et al., 2006). In Australia, most of the human population growth is near the coast, with 85% of the population currently living within 50 km of the coastline (Clark and Johnston, 2016). As a result, the demand for industrial and residential infrastructure, shipping, aquaculture, and tourism activities has accelerated rapidly and so too has the pressure on marine mammals inhabiting coastal waters (Hawkins et al., 2017). This is particularly the case for north Western Australia (WA), where large-scale coastal habitat modification to support expansion of mining and petroleum industries has occurred (and is increasing), and assessment of the impacts to coastal dolphins continues to be limited due to a lack of baseline information (Preen et al., 1997, Allen et al., 2012, Bejder et al., 2012, Brown et al., 2012, Hanf et al., 2016).

The coastal waters of the North West Cape (NWC) experience variable levels of protection, with waters to the West and North of the NWC falling within the Ningaloo Coast World Heritage Area (NCWHA) and the Ningaloo Marine Park (Commonwealth and State Waters) (NMP). Australia provides a high degree of protection to its World Heritage properties and marine parks. Three levels of Government (National, State, and Municipal) work in conjunction with community, indigenous custodians and the Ningaloo Coast World Heritage Advisory Committee to manage and maintain the World Heritage values of the area (DoEWHA, 2010). The NMP is a single marine protected area with an ecosystem-based management approach managed under a cooperative arrangement. Only approved commercial and recreational activities that are consistent with the conservation and restoration of the natural environment are permitted in these waters (DoEWHA, 2010). The State waters extend to three nautical miles from the reef and are divided into different zones with different restrictions (General Use, Special Purpose, Recreational and Sanctuary Zones) (DoEH, 2002). The Commonwealth waters extend to another 3–9 nautical miles from the State waters and are managed with uniform restrictions throughout (DoEH, 2002). On the eastern side of the NWC lies the Exmouth Gulf, which although is recognized as an important ecosystem, lacks formal protection.

Due to the outstanding natural values of the NCWHA and NMP, the NWC has been subject to a large magnitude of scientific research with variable areas of interest (i.e., geomorphology of the area, benthic ecology, marine flora and fauna, oceanography and the social impacts of tourism in the area among others). The area also supports a substantial marine megafauna wildlife tourism industry (Sanzogni et al., 2015, Raudino et al., 2016), a major humpback whale (*Megaptera novaeangliae*) nursery (Bejder et al., 2019), a high density of threatened Australian humpback dolphins

(*Sousa sahulensis*) (Hunt et al., 2017) and WA's second largest prawn fishery (Pitcher et al., 2016, Kangs et al., 2006).

The IP bottlenose dolphin (*Tursiops aduncus)* is known to occur in the coastal waters of the NWC (Allen et al., 2012, Hanf, 2015, Brown et al., 2012). Australian humpback and IP bottlenose dolphins are recognized as being of ecological value to the biodiversity of the NMP, the NCWHA (CALM and MPRA, 2005, DBCA, 2018) and north WA in general (DoE, 2015), but targeted ecological studies have so far only focused on the Threatened humpback dolphins (Hunt et al., 2017, Hunt, 2018, Hunt et al., 2019). IP bottlenose dolphins are currently listed as Near Threatened by the International Union for the Conservation of Nature (IUCN) (Braulik et al., 2019). The lack of information on the ecology of this species in north WA has prevented an accurate assessment of their conservation status, hampering management and conservation decisions.

In this study, I used capture-mark-recapture methods and population models to investigate site fidelity patterns (i.e. the tendency of dolphins to remain in, or return to, and reuse the study area) and estimate abundance of IP bottlenose dolphins around the NWC whilst taking into account the presence of non-resident individuals. Results from this study provide important information on the population demographics of IP bottlenose dolphins at the NWC that will aid their future conservation and management.

## 2.3 Methods

### *2.3.1 Study site*

The study area encompasses the coastal waters surrounding the North West Cape (NWC) peninsula located north-west of the Australian mainland (Figure 2.1). The NWC study area is located in the northern section of the Ningaloo Reef (Australia's largest fringing reef). Two-thirds of the total study area falls within the protected Ningaloo Marine Park (NMP) (State Waters) (Figure 2.1).

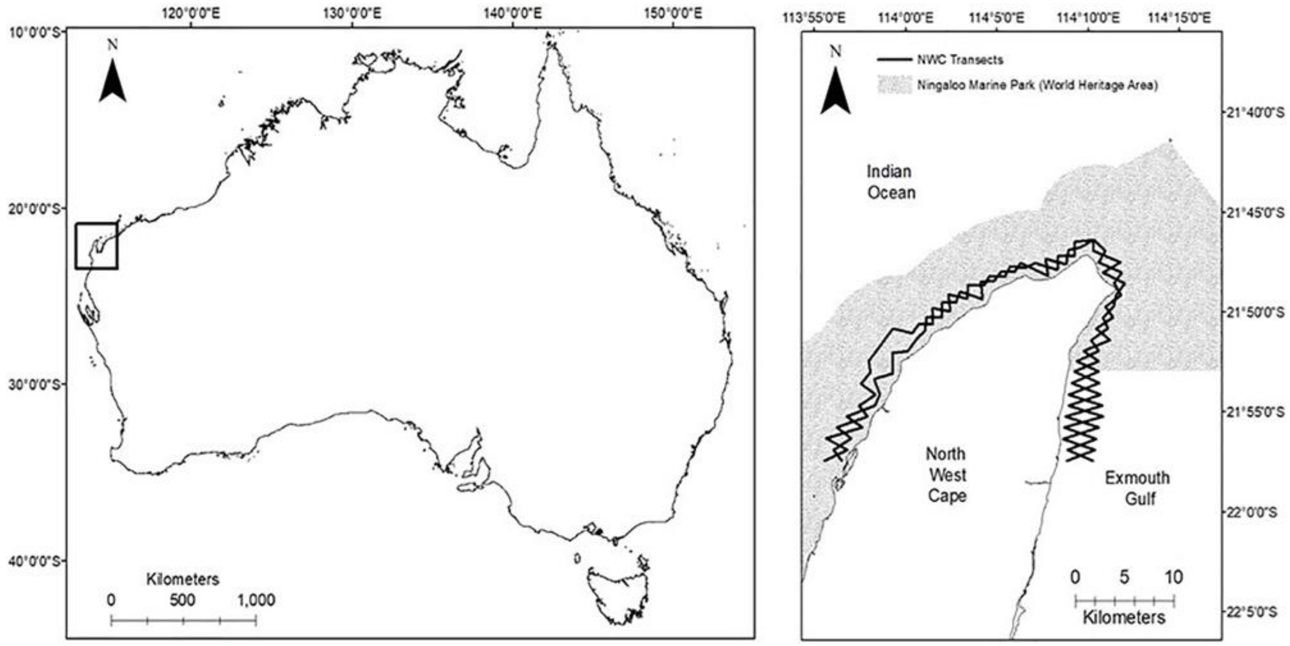


**Figure 2.1:** Map of Australia, showing the location of the North West Cape (pictured inside box). (Right) The North West Cape study site and opposing zigzag line transect sampling design (2 x 93 km in length).

### *2.3.2 Data collection*

Boat-based surveys targeting both Indo-Pacific (IP) bottlenose dolphins and Australian humpback dolphins were conducted in favourable weather conditions (Beaufort Sea State ≤3 and no rain) with six 3-month long sampling periods conducted over 3 years (2013–2015) covering the austral seasons of autumn (April–

June), winter (July–August), and spring (September–October). The 3-month long sampling periods spanned over multiple austral seasons and for the purpose of examining any seasonal changes in abundance in this study were classified as either autumn/winter (AW) (April–June) or winter/spring (WS) (July–October). Summer and early autumn months (November– February, and March, respectively) were not surveyed due to consistently unfavourable wind conditions, the higher risk of tropical cyclones and extreme temperatures. Surveys were conducted from 0700 to 1800 h (depending on suitable conditions) on board a 5.6 m centre console aluminium vessel with a 100 HP outboard motor. Surveys followed a systematic line transect layout which was developed based on accessibility and in order to adequately sample the wide range of habitats, human use areas and environmental variables within the study area. The transect layout consisted of two 93 km long opposing zig-zag lines (Figure 2.1). The study area covered approximately 130 km$^2$ along 50 km of coastline, and extended up to five km offshore, encompassing water depths up to 45 m.

During surveys a crew of three to five (mode = four) observers searched for dolphins forward of the vessel's beam, alternating between the naked eye and 7 × 50 binoculars. Schools of dolphins were defined as dolphins with relatively close spatial cohesion (i.e., each member within 100 m of any other member) involved in similar (often the same) behavioural activities [modified from Connor et al. (1998)]. When a dolphin school was sighted, survey effort was suspended and dolphins were slowly approached to within 30 m to collect photo-identification images and record location (using a GPS unit), school size, school age composition (number of calves, juveniles, and adults) and predominant school behaviour (i.e. behavioural state in which more than 50% of the animals in a school are involved;Mann, 1999). All dolphins within a school were photographed regardless of their level of marking. The three age classes were distinguished based on behavioural cues and visual assessment using the average adult size as a reference: (1) adults: individuals >2 m long; (2) juveniles: individuals between 1/2 and 2/3 the body length of an adult, usually swimming in close association with an adult, but sometimes swimming independently; and (3) calves: animals ≤1/2 the length of an adult, in close association with an adult, and swimming regularly beside or slightly behind an adult. Once all individuals within a school were photographed or sight of dolphins was lost, the boat returned to the transect line where dolphins were first sighted and resumed survey effort. All data were collected under permit and with ethics approval.

### *2.3.3 Photo-identification*

All photographs taken were processed using the DISCOVERY photo-identification data-management system software (Gailey and Karczmarski, 2012). Images were examined and scored according to strict quality and distinctiveness protocols (For full details of these protocols, see S1.1 in Appendix 1 of this thesis). To develop capture histories of individuals and for all subsequent analyses, I used only images of distinctive (D1 and D2) adult individuals deemed to be of excellent and good quality. Juveniles and calves were excluded due to their lack of distinctive markings and dependence on their mothers, violating common model assumptions that captures are independent (Pollock et al., 1990).

### *2.3.4 Proportion of marked individuals*

The proportion of identifiable individuals in the study population (θ) was determined by dividing the number of recognisable (D1 and D2) individuals by the total number of individuals observed in each encounter, averaged over all encounters (Silva et al., 2009, Gore et al., 2016). Abundance estimates and confidence intervals were adjusted considering the proportion of marked individuals in the study population using the following formula:

$$\text{Marked Individuals} = \frac{\text{D1} + \text{D2 individuals in a sighting}}{\text{Total individuals in a sighting}}$$

### *2.3.5 Site fidelity*

I investigated the monthly, sampling period, and yearly sighting rates of individuals to determine the tendency of dolphins to return to the study area (Zanardo et al., 2016, Hunt et al., 2017, Passadore et al., 2017).

1. Monthly sighting rate: the number of months an individual was identified as a proportion of the total number of study months. Monthly sighting rates could range between 0.05 (i.e., animals sighted in only 1 month out of the 19 months surveyed) and 1 for an individual sighted in all months.
2. Sampling period sighting rate: the number of 3-month long sampling periods an individual was identified as a proportion of the total number of sampling periods in this study. Sampling period sighting rates could range between 0.16 (i.e., animals sighted in only one sampling period out of the six sampling periods) and 1 for an individual sighted in all sampling periods.
3. Yearly sighting rate: the number of years an individual was identified as a proportion of the total number of study years. Yearly sighting rates could range between 0.33 (i.e., animals sighted in only 1 year out of the 3 years surveyed) and 1 for an individual sighted in all years.

I used Pearson's correlation to quantify the relationship between the three individual site fidelity measures using R version 3.4.4 (R Core Team., 2018). The variables with the lowest level of correlation were analysed using agglomerative hierarchical clustering (AHC) (Legendre and Legendre, 2012), to assess if there were clusters of individual dolphins who exhibited similar patterns of site fidelity. AHC analysis was run in Primer/PERMANAOVA + v7 software using Euclidean distance as the dissimilarity measure. For each cluster identified, I used Primer to calculate *p*-values to determine statistical significance (at 5% significance level), assess the confidence in the strength of each of the clusters identified and to specify a dissimilarity threshold to represent the most appropriate number of clusters. To assess how faithfully clusters in the dendrogram represented the dissimilarities among observations, I used the cophenetic correlation coefficient (CPCC), with a CPCC-value >0.8 indicating a reliable representation of the data (Sokal and Rohlf, 1962).

Additionally, I calculated a standardised site fidelity index (SSFI) at the population level using the following formula (Tschopp et al., 2018):

$$\mathrm{IT} = \frac{\mathrm{IT\ individual\ 1} + \mathrm{IT\ individual\ 2\ \ldots}}{\mathrm{Total\ number\ of\ individuals}}$$

and

$$\mathrm{It} = \frac{\mathrm{It\ individual\ 1} + \mathrm{It\ individual\ 2\ \ldots}}{\mathrm{Total\ number\ of\ individuals}}$$

followed by:

$$\frac{2}{\frac{1}{\mathrm{IT}} + \frac{1}{\mathrm{It}}}$$

where *IT* (Permanence) is the amount of time in the study area expressed as the average number of days between the first and last capture of each individual as a proportion of the total number of days from the beginning to the end of sampling (non-constant effort). *It* (Periodicity) is the average recurrence of an individual, expressed as an inverse fraction of the number of days between an individual’s first, and last capture as a proportion of the individual’s total number of captures minus one. The SSFI varies between zero (indicating low site fidelity for the population) and one (indicating high site fidelity for the population).

### *2.3.6 Abundance, density, and apparent survival of Individuals*

Estimating demographic parameters of highly mobile and wide-ranging species is difficult, particularly when dealing with populations containing a high proportion of "non-resident" or "transient" individuals. Site fidelity analysis suggested the population was open to individual movement within and between sampling periods, and tests of population closure conducted in CloseTest (Stanley and Burnham, 1999) indicated the population was not closed (Otis test *p*-value = 0.99854 and Stanley and Burnham test *p*-value = 0.00). To overcome the challenges posed by the high levels of transience within this population, two different open population-modeling techniques [POPAN and a maximum likelihood estimation (MLE) transient model] were chosen to quantify baseline population demographics of the IP bottlenose dolphins inhabiting the study area.

Abundance of IP bottlenose dolphins across the six sampling periods (Table 2.1) in the study area was estimated using a POPAN parameterisation of the Jolly–Seber model (Schwarz and Arnason, 1996). This model provides abundance estimates while allowing entries (i.e., births and immigration) and losses (i.e., death and permanent emigration) in the population under study and is suitable for long-term studies where the use of models assuming population closure is not reasonable. POPAN models were run in Program MARK (White and Burnham, 1999) and estimated super-population size (*N*) (i.e., the number of animals that theoretically used the study area during the course of the study, including those not captured (Schwarz and Arnason, 1996), apparent survival (*phi*), capture probability (*p*) and the probability of an individual from the super-population entering the sampled population for that sampling occasion (*pent*). Due to the nature of the sampling design (six 3-month long sampling periods spaced over 3 years) and weather constraints, time intervals between sampling periods were uneven. Time intervals were calculated as the number of days between the last day of the previous period to the first day of the corresponding period as a yearly proportion and were accounted for in the models. I ran a total of eight models allowing for fixed (•) or time-varying (*t*) effects on *phi*, *p* and *pent* in the study area throughout the survey period (For model details see S1.2 in Appendix 1 of this thesis). The most parsimonious model was selected based on the Quasi Akaike Information Criterion (QAICc) values (Burnham and Anderson, 2002).

I also used a MLE transient model (Conn et al., 2011) to estimate the abundance of resident individuals ($N^{Res}$) and the super-population size (*N*, combined abundance of resident and non-residents). The model assumes that individuals sampled more than once were residents, and individuals only seen once were either resident individuals that by chance were only observed once or non-residents, which had entered the study area and become available for sampling. Four maximum likelihood transient models were run in R (R Core Team., 2018) using the package DeRiv [R code obtained from Conn et al. (2011)] allowing for fixed (•) or time-varying (*t*) effects on *Pit* and π*t* in the study area throughout the survey period. These models estimated super-population size ($N^*$), the probability that an individual selected at random is a resident (α), capture probability (*Pi*), probability of transients entering the study area and becoming available for sampling (π), and the population size of residents ($N^{res}$). The most parsimonious model was selected based on AICc values (For full model details see S1.3 in Appendix 1 of this thesis).

### *2.3.7 Goodness of fit and validation of model assumptions*

Goodness of fit of the POPAN model was calculated using program RELEASE in MARK and program U-CARE with chi−squared tests (and Fisher’s exact tests when needed) for transients and trap−dependence (Lebreton et al., 1992). First, T3. SR considered individuals seen in a particular sampling period, and how many were then seen again and when, essentially testing for transience in the population. Second, Test 3. SM tested for a difference in individuals in the time between an individual's first capture and its first recapture. Third, Test 2. C (program RELEASE) and Test 2. CT (program U-CARE), tested for trap dependence. Fourth, a global test (Test 2 + 3) tested for homogeneity in individual capture histories. I estimated the variance inflation factor (c) to quantify over-dispersion in the data using the chi-square statistic divided by its degrees of freedom. Goodness of fit tests for the MLE transient model have not yet been developed.

POPAN and the MLE transient model have a few assumptions, which if violated can lead to bias in population estimates (Pollock, 1982, Pollock et al., 1990, Kendall and Bjorkland, 2001, Conn et al., 2011). I used population information obtained in this study, information on dolphin biology and ecology and evaluated the study design in combination with a variety of tests to validate the assumptions of these models (For more detail see S1.4 in Appendix 1 of this thesis).

## 2.4 Results

### *2.4.1 Survey effort, photo-identification, and proportion of marked individuals*

A total of 283 h of survey effort was completed across the six sampling periods over the 3 years (2013–2015) of this study (Table 2.1). During this time, 182 schools of Indo-Pacific (IP) bottlenose dolphins were sighted, ranging in size from 1 to 30 individuals (mean ± SD = 6.42 ± 5.22). The cumulative discovery curve of identified individuals (Figure 2.2) continued to gradually increase over the 3-year study period indicating that new individuals were continually sighted within the study area. A total of 184 distinctly marked individuals were photo-identified and included in statistical analysis. The proportion of marked individuals within the study population (θ ± SE) was estimated at 0.80 ± 0.36.

**Table 2.1:** Summary of survey effort, number of schools of Indo-Pacific bottlenose dolphins sighted and number of marked individuals identified per sampling period around the North West Cape, Western Australia, between 2013 and 2015.

| Sampling period (season) | Time period (dd/mm/yyyy) | Number of survey days | Survey effort (hours) | No. of schools sighted | No. of animals identified |
|---|---|---|---|---|---|
| 1 (AW) | 28/05/2013-15/07/2013 | 17 | 22.5 | 18 | 45 |
| 2 (WS) | 26/08/2013-17/10/2013 | 16 | 11.7 | 15 | 45 |
| 3 (AW) | 09/04/2014-06/07/2014 | 38 | 70.4 | 45 | 93 |
| 4 (WS) | 31/07/2014-07/10/2014 | 39 | 69.9 | 44 | 78 |
| 5 (AW) | 03/05/2015-05/07/2015 | 28 | 42.6 | 26 | 40 |
| 6 (WS) | 29/07/2015-26/10/2015 | 33 | 65.5 | 34 | 46 |
| Total | | 171 | 282.6 | 182 | 184 |

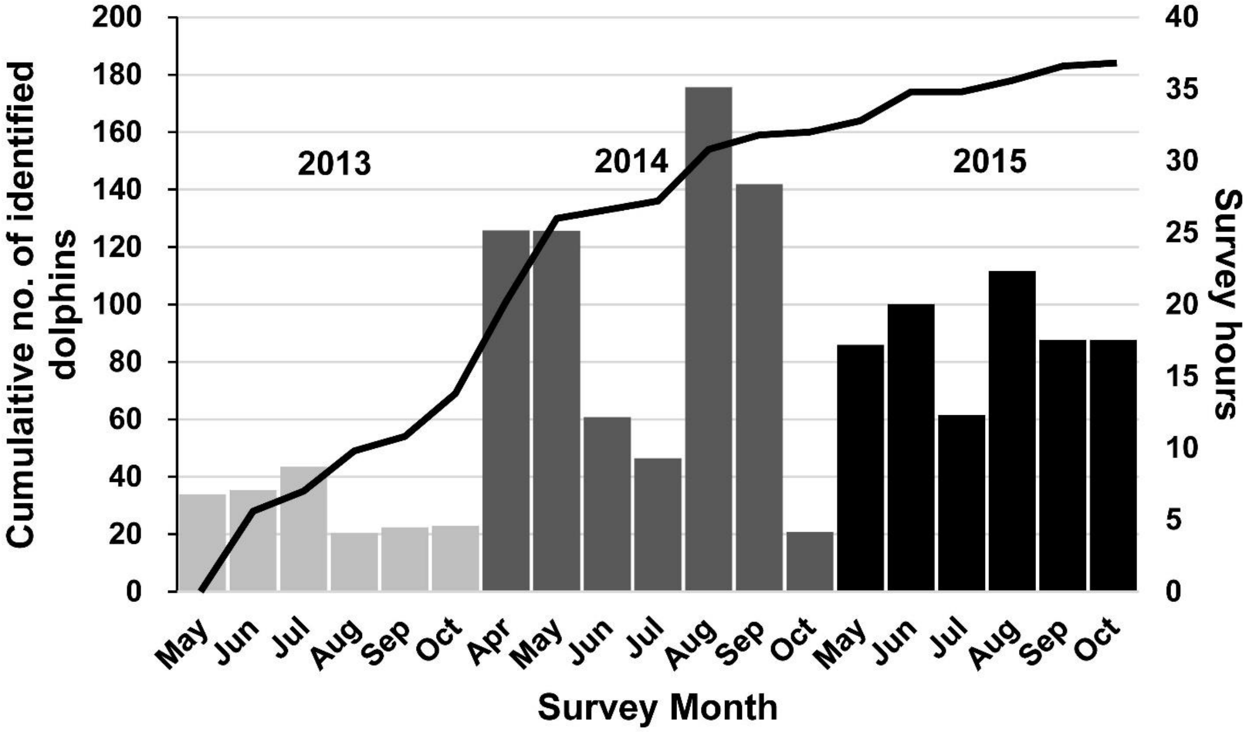


**Figure 2.2:** Cumulative discovery curve of identified Indo-Pacific bottlenose dolphins (n=184) within the North West Cape study area in Western Australia over 2013 (May- October), 2014 (April-October) and 2015 (May-October) survey periods (total 171 days). Columns represent the number of survey hours during each month of study.

### *2.4.2 Site fidelity*

Of the 184 individuals photo-identified, 73 (40%) were sighted only once, 62 (34%) individuals were sighted either two or three times, and 49 (27%) were sighted four or more times (mean ± SD = 3.11 ± 3.11). The average monthly resight rate (±SD) was 0.13 ± 0.10 (95% CI: 0.11–0.14) indicating individuals were typically sighted in two out of 19 months surveyed. Only four individuals were sighted in more than 50% of the total months surveyed, and no individual was seen in all 19 months. The average yearly resight rate was 0.52 ± 0.24 (95% CI: 0.48–0.55) indicating that individuals were more commonly sighted in either one or two of the three surveyed years. In total, 107 individuals were sighted in only 1 year, 52 in 2 years and 25 in all 3 years.

The average sampling period resight rate (±SD) was 0.32 ± 0.19 (95% CI: 0.29–0.35) showing that individuals were typically sighted in two out of the six sampling periods. Two individuals were seen in all six sampling periods and 94 individuals were only seen in one. Eighteen individuals were seen in over 50% of sampling periods (four or more sampling periods). The standardised site fidelity index (SSFI) estimate was 0.019 indicating very low levels of site fidelity at the population level in the study area.

The correlation test found that sampling period resight rate was highly correlated with both the monthly and yearly resight rates (0.92 and 0.88, respectively). Agglomerative hierarchical clustering (AHC) clustering analysis was run using only the monthly and yearly resight rates which had a correlation of 0.76. AHC analysis separated individuals into three main clusters (largest dissimilarity threshold = 0.6). The cophenetic correlation coefficient (CPCC = 0.94) and *p*-values (0.001 at 5% significance level) indicated a strong representation of the dissimilarities among observations (Figure 2.3). Cluster 1 contained 25 individuals (14%) that were sighted in all 3 years of survey; cluster 2 contained 52 individuals (28%) that were sighted in 2 years of survey and cluster 3 contained 107 individuals (58%) seen in only 1 year. Thus, cluster 1 individuals are considered to be “full-time residents”, who display a high level of residency to the study area, cluster 2 are considered to be “part-time residents,” who were sampled more than once but display a lower level of site fidelity to the study area than the full-time residents and cluster 3 are considered to be “non-residents” (“transients”) with no site fidelity to the study area. For the purpose of this study, I considered residents as individuals of clusters 1 and 2 and non-residents as individuals of cluster 3. Average resight rates and standard deviations of the three clusters are shown in Table 2.2.

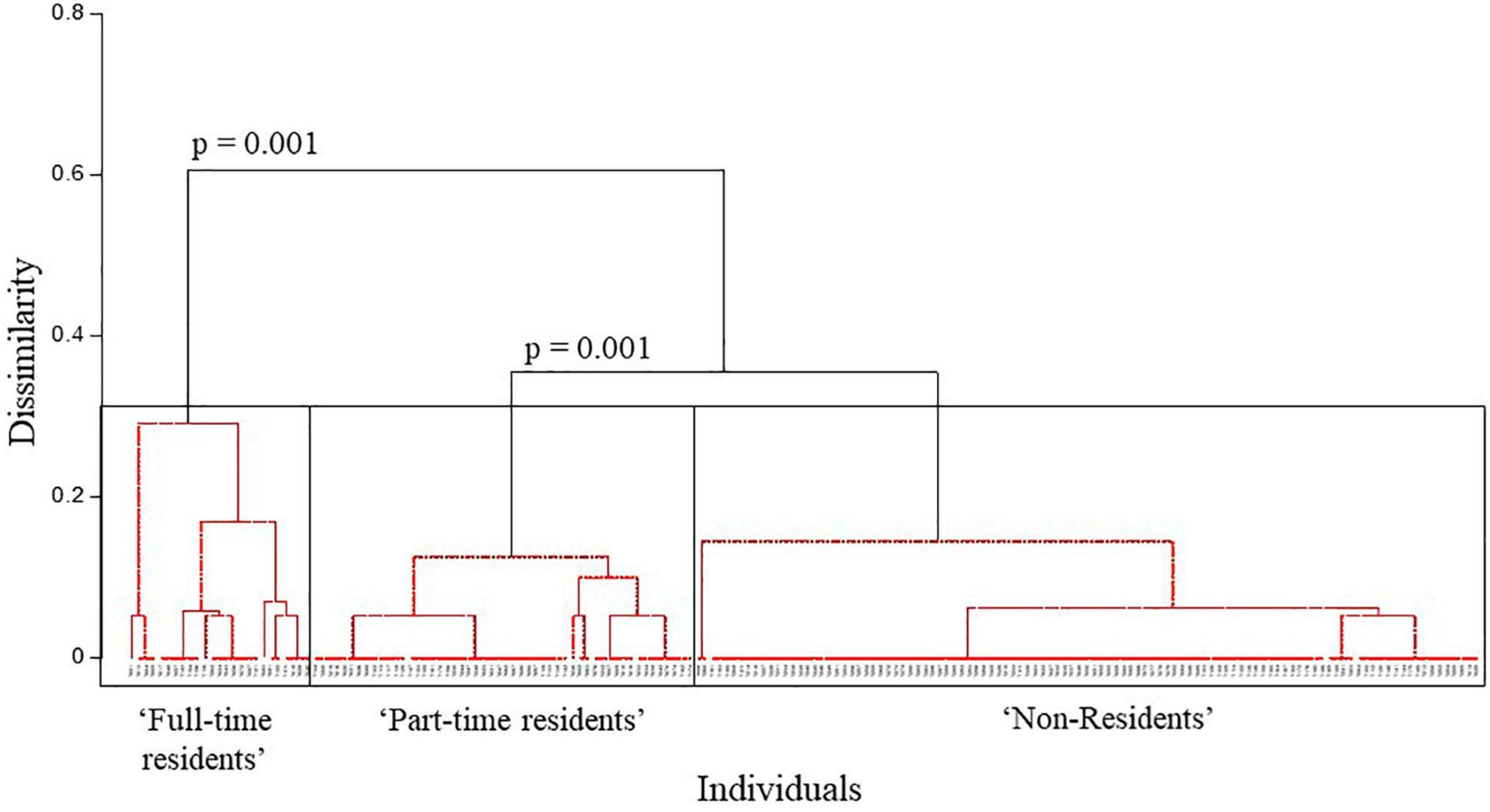


**Figure 2.3:** Agglomerative hierarchical clustering analysis displaying three main clusters based on the site fidelity patterns of the Indo-Pacific bottlenose dolphins of the North West Cape, Western Australia ("Full-time residents", "Part-time residents", and "Non-residents") with the largest dissimilarity threshold = 0.6.

**Table 2.2:** Average monthly and yearly resight rates of the three clusters (“Full-time residents”, “Part-time residents”, and “Non-residents”) of Indo-Pacific bottlenose dolphins identified through agglomerative hierarchical clustering analysis at the North West Cape, Western Australia.

| Cluster | Average monthly resight rate (SD) | Average yearly resight rate (SD) |
|---|---|---|
| 1 ‘Full-time residents’ | 0.29 (±0.14) | 1 (±0.00) |
| 2 ‘Part-time residents’ | 0.17 (±0.07) | 0.67 (±0.00) |
| 3 ‘Non-residents’ | 0.07 (±0.03) | 0.33 (±0.00) |

### *2.4.3 Abundance, density, and apparent survival of individuals*

Results from POPAN models were averaged (Table 2.3) to account for model selection uncertainty (see S1.2 in Appendix 1 of this thesis for unadjusted unaveraged AICc models and unaveraged QAICc models). Certain parameters are inestimable for sampling periods one and six so only sampling periods two, three, four and five are displayed in Table 2.3.

**Table 2.3:** POPAN estimates of population size (*N*), apparent survival (*Phi*), capture probability (*p*), and probability of entry into the population (*pent*) of Indo-Pacific bottlenose dolphins around the North West Cape in Western Australia for each sampling period.

| Sampling period (season)* | Nm (95% CI) | $N_{Super}$ (95% CI) | Survival (*Phi*) (95% CI) | Recapture probability (*p*) (95% CI) | Probability of entry (*pent*) (95% CI) |
|---|---|---|---|---|---|
| 2 (AW) | 132<br>(59-205) | 165<br>(74-256) | 0.77<br>(0.15-0.98) | 0.37<br>(0.19-0.60) | 0.23<br>(0.04-0.70) |
| 3 (WS) | 170<br>(116-223) | 213<br>(145-279) | 0.25<br>(0.02-0.87) | 0.57<br>(0.33-0.78) | 0.05<br>(0.00-0.51) |
| 4 (AW) | 154<br>(103-206) | 193<br>(129-258) | 0.65<br>(0.07-0.98) | 0.50<br>(0.32-0.68) | 0.07<br>(0.01-0.35) |
| 5 (WS) | 135<br>(58-212) | 169<br>(73-265) | 0.80<br>(0.12-0.99) | 0.33<br>(0.14 – 0.60) | 0.04<br>(0.00-0.35) |
| Average^ | 249<br>(199-298) | 311<br>(249-373) | 0.62<br>(0.55-0.1.05) | 0.44<br>(0.33-0.55) | 0.09<br>(0.01-0.18) |

* The first and last sampling period parameters are not listed here due to the confounding that arises from not being able to estimate all parameters before an individual's first capture and after their last capture.

^Averages are displayed for *Phi, p* and *pent* parameters. $N_m$ and $N_{super}$ are displayed as total estimates for the entire sampling period.

Model averaged results estimated that the total super-population size across the study period was *N* = 311 (95% CI: 249–373), average apparent survival (*phi*) = 0.62 (95% CI: 0.55–1.05), average recapture probability (*p*) = 0.44 (95% CI: 0.33–0.55), and the average probability of entry (*pent*) = 0.09 (95% CI: 0.01–0.18) (Table 2.3).

The transient maximum likelihood estimation (MLE) model with the lowest AICc (AICc = 1234.001) was the one with time varying capture probability (*p*) and constant entry probabilities (π) (see S1.3 in Appendix 1 of this thesis). The super-population size of marked individuals was estimated at 296 (95% CI: 259–333) and resident population size at 113 (95% CI: 93–133). The total super-population and resident population size after accounting for both unmarked and marked individuals was 370

(95% CI: 333–407) and 141 (95% CI: 121–161), respectively. The probability that an individual selected at random is a resident (α) was 0.38.

Density of IP bottlenose dolphins within the 130 km$^2$ North West Cape (NWC) study area using the abundance estimates from POPAN and transient MLE models (taking into account the proportion of marked individuals) was estimated at an average of 2.4 and 2.8 dolphins per km$^2$, respectively.

### *2.4.4 Goodness of fit*

Test 3. SR from RELEASE and U-CARE for the POPAN model indicated a transient effect in the population, which was expected after visual inspection of individual capture histories, site fidelity analyses and the results of the CloseTest. Test 3.SM showed no strong evidence to reject temporal heterogeneity in capture probabilities; Test 2.C (RELEASE) and Test 2.CT (U-CARE) showed no strong evidence to reject the null-hypothesis of no trap dependence. The global test (Test 2 + 3) showed no homogeneity in individual capture histories with 42 unique capture histories indicating that there is a large amount of variation in detection of individuals, likely due to the high proportion of non-residents. RELEASE and U-CARE estimated the variance inflation factor (c) as 2.28 and 2.37, respectively, indicating over dispersion of the data. In response to this, AICc values were adjusted to QAICc values (Richards, 2008). RELEASE and U-CARE goodness of fit test results are displayed in Table 2.4.

**Table 2.4:** Results from goodness of fit tests run in Program RELEASE and U-CARE for the sampling periods of Indo-Pacific bottlenose dolphin surveys conducted during 2013-2015 around the North West Cape, Western Australia.

| **Program** | **Parameters** | **Test 3.SR** | **Test 3.SM** | **Test 2.CT** | **Global Test** | **$\hat{c}$** |
|---|---|---|---|---|---|---|
| RELEASE | $X^2$ | 17.12 | 2.50 | 3.18 | 22.80 | 2.28 |
| | df | 4 | 3 | 3 | 10 | |
| | p-value | 0.0018 | 0.4752 | 0.3654 | 0.0115 | |
| U-CARE | Statistic | 4.30 | N/A | 0.89 | N/A | 2.37 |
| | $X^2$ | 19.31 | 5.41 | 3.72 | 28.44 | |
| | Df | 4 | 4 | 3 | 13 | |
| | p-value | 0.0006838 | 0.24746 | 0.29377 | 0.0078605 | |

## 2.5 Discussion

In this study, I provide the first assessment of baseline population demographic parameters (site fidelity, abundance, and survival) of Indo-Pacific (IP) bottlenose dolphins in the coastal waters of the North West Cape (NWC), Western Australia (WA). I provide relevant information to aid the management of a large population inhabiting an area of multiple use (wildlife tourism, scientific research, recreational activities, fisheries and resource extraction in neighbouring waters) with mixed levels of protection. Site fidelity and abundance estimates indicated that the population of IP bottlenose dolphins using the coastal waters of the NWC is composed of a large proportion of animals that use the area occasionally, and a smaller proportion of animals that use the area regularly. An average of 2.4 – 2.8 dolphins per km$^2$ reside in the coastal waters of the NWC, with a resident population of 141 individuals using the area year round. The low site fidelity displayed by a large proportion of individual dolphins, and slight variation in abundance estimates across sampling periods indicated that animals range beyond the limits of the study area. Despite the low levels of site fidelity observed, the high number of animals (both residents and non-residents) using the study area over time suggests that the NWC represents an important habitat within the home range of this species.

### *2.5.1 Site fidelity*

Worldwide, bottlenose dolphin populations (*Tursiops sp*.) display variation in their patterns of occurrence, distribution and site fidelity. Within a population, individuals have been observed showing varying levels of residency with individuals typically characterized as residents, migratory (semi-resident) or transient (non-resident). High levels of site fidelity and residency are characteristic of bottlenose dolphins in protected coastal areas with high prey availability and low predation risk (Gowans et al., 2007, Fury and Harrison, 2008, Chabanne et al., 2012, Webster et al., 2014, Brown et al., 2016, Zanardo et al., 2016, Dulau et al., 2017, Passadore et al., 2018b). In contrast, low levels of site fidelity is often typical of individuals inhabiting lower productivity areas where prey availability is highly variable in space and time (Gowans et al., 2007, Silva et al., 2008, Edwards et al., 2009, Lafontaine et al., 2017b).

The distribution of prey has been identified as one of the key factors influencing species distribution and movement (Shane et al., 1986, Hanson and Defran, 1993, Hart, 1997, Browning et al., 2014). The large proportion of non-resident individuals found at the NWC likely reflects high spatial and temporal variability in their prey resources. The coastal lagoon waters to the west of the Cape are influenced by two opposing current systems. The southward Leeuwin current is prevalent from April to September moving warm, low nutrient waters down the coast (Sleeman et al., 2007, Hanson and McKinnon, 2009). From September to April, strong southerly winds generate a northward current (Ningaloo Current) which creates an upwelling of cooler, higher nutrient waters from below the Leeuwin current (Sleeman et al., 2007, Hanson and McKinnon, 2009). The change in oceanographic conditions between seasons could potentially drive a shift in prey availability or preferable environmental conditions. A similar environment in North Central Chile which experiences productive upwelling driven by southward winds in summer, and a down welling of less productive waters in winter, is also home to a population with a large proportion of transient individuals (Santos-Carvallo et al., 2018). Transient individuals tended not to be present during unproductive winter months, likely as a result of a decrease in food supply (Santos-Carvallo et al., 2018). The diet of the IP bottlenose dolphins at the NWC is currently unknown and should be a topic of future research to further understand the distribution of IP bottlenose dolphins around the NWC.

Dietary divergence, differential use of space and habitat selection have been proposed as some of the major resource partitioning mechanisms promoting the coexistence of sympatric delphinids (Bearzi, 2005, Parra, 2006). The NWC apart from holding a large population of IP bottlenose dolphins, is also home to a dense and sizeable population of Australian humpback dolphins (129 individuals 95% CI: 117–141, 0.90–1.09 individuals per km$^2$) (Hunt et al., 2017). In contrast to the IP bottlenose dolphins, Australian humpback dolphins have high levels of site fidelity and high residency to the NWC (Hunt et al., 2017). Australian humpback dolphins at the NWC showed a preference for shallow waters (5 – 15 m deep) up to 2000 m from the coast (Hunt, 2018). Habitat preferences of the IP bottlenose dolphins in these waters is a topic of current research. Differences in space use and habitat selection between humpback and IP bottlenose dolphins may be the principal mechanisms promoting their coexistence, which could be a possible explanation for low site fidelity of the IP bottlenose dolphins to the NWC.

In a number of bottlenose dolphin (*Tursiops sp*.) populations, individuals have segregated into different communities to cope with intraspecific competition (Wells, 1986, Rossbach and Herzing, 1999, Chilvers and Corkeron, 2001, Urian et al., 2009). These distinct communities may overlap in diet and home range and live in direct sympatry (Chilvers and Corkeron, 2001, Lusseau et al., 2006) or they may show different ranging patterns (Urian et al., 2009, Kiszka et al., 2012). It has been hypothesised that these communities have formed in order to optimise space and resource sharing (Kiszka et al., 2012). It is possible that the IP bottlenose dolphin population in the NWC consists of multiple communities that have formed to reduce space and resource competition. Studies involving stable isotope analysis, home range patterns and genetic sampling of the resident and non-resident individuals could be used to investigate this further.

Predation risk is also known to influence dolphin distribution and habitat use, which could influence the site fidelity of individuals to a particular area (Wirsing et al., 2008, Kiszka et al., 2015). Killer whales (*Orcinus orca*), as well as tiger sharks (*Galeocerdo cuvier*); well−known predators of marine mammals including dolphins, are known to inhabit the waters of the NWC (Pitman et al., 2015). Successful predation attempts from killer whales on IP bottlenose dolphins have been reported by ecotourism charters in Coral Bay (100 km south) and several individuals of the NWC population exhibit scars and fresh wounds as a result of shark bites (Haughey, personal observations). Therefore, a high predation risk could be a possible explanation for low site fidelity of IP bottlenose dolphins to the NWC.

Movements of bottlenose dolphins along the northwest coast of WA are poorly understood. The large number of non-resident individuals within NWC waters suggests IP bottlenose dolphins frequently use areas beyond the study area. The presence of IP bottlenose dolphins in coastal waters adjacent to the NWC (Haughey, personal observations), and further offshore within the central and eastern parts of the Exmouth Gulf (Preen et al., 1997, Sleeman et al., 2007, Hanf, 2015), as well as in Coral Bay to the south and Onslow to the north (approx. 100 km either direction) (Allen et al., 2012, Raudino et al., 2018) suggest that movements beyond the study area are likely. Future monitoring of IP bottlenose dolphins integrating photo-identification, genetics, and telemetry in NWC and adjacent waters would shed further insight into their population boundaries, site fidelity and home range.

### *2.5.2 Abundance of individuals*

Dolphin abundance is typically influenced by the abundance and distribution of their prey and predators and habitat type, with protected and enclosed areas containing typically smaller populations than those that occupy semi-open habitats (Shane et al., 1986, Wells et al., 1987, Ballance, 1992). Differences in the methodologies used and sizes of study areas makes comparison of abundance estimates amongst studies difficult. Most estimates of abundance for other areas in Australia of similar size to the study area (130 km$^2$) and generated using similar methodologies (photo-identification and capture-recapture models) range in size from 63 individuals to 160 individuals (Möller et al., 2002, Smith et al., 2013, Brown et al., 2016, Raudino et al., 2018) with the exception of Point Lookout, Australia, with estimates of 861–895 individuals (Chilvers et al., 2003). The NWC abundance estimates of 311–370 individuals are larger than most of these studies and thus indicate a moderately large population inhabits these waters. The NWC study area offers both protected and enclosed waters to the east in the Gulf, and semi open oceanic waters with lagoons on the inner side of the Ningaloo Reef to the west. Access to both open and enclosed habitats within the study area may explain the relatively large mix of resident and non-resident individuals inhabiting the NWC, further highlighting the need to study the adjacent waters of the Exmouth Gulf. The high abundance of both resident and non-resident individuals in NWC across seasons also suggests this area offers highly favourable year−round habitat conditions.

### *2.5.3 Apparent survival and permanent emigration of Individuals*

Due to the high longevity of IP bottlenose dolphins, I acknowledge that a 3-year study may not fully encapsulate the population processes of emigration and mortality and suggest that long-term monitoring of this population is needed to get a better baseline estimate of apparent survival. Survival is a key demographic parameter that is difficult to estimate from capture-recapture data, as models cannot separate mortality from permanent emigration (Ergon and Gardner, 2014). This difficulty is heightened when looking at species with high longevity and low levels of site fidelity. Unless site fidelity to a particular study area is very high, apparent survival is usually under estimated (Schaub and Royle, 2014). The level of underestimation depends on the size of the study area and the ranging patterns of the species (Zimmerman et al., 2007). If the geographical limits of a study area correspond perfectly with the ranges of the population of interest, treating both permanent emigration and survival as one parameter may be appropriate (Gilroy et al., 2012). However, if the study area falls within a wider area of interest, permanent emigrants surviving outside the study area may still have the potential to contribute to population processes (Gilroy et al., 2012). As discussed above, the low levels of site fidelity observed in this study and the presence of IP bottlenose dolphin in adjacent waters indicates that individuals range beyond the limits of the 130 km$^2$ study area. The low average estimate of survival presented in this study (0.62, 95% CI: 0.55–1.05) is likely a result of the high proportion of individuals only seen once and is therefore more likely to be representative of permanent emigration and transience than survival.

### *2.5.4 Model selection and evaluation of model reliability and performance*

Both POPAN and the maximum likelihood estimation (MLE) transient models have their advantages and limitations, with the only mutually estimable parameter being abundance (see sections *2.3.6 Abundance, density, and apparent survival of Individuals, 2.3.7 Goodness of fit and validation of model assumptions* and S1.4 in Appendix 1 of this thesis). The two models produced abundance estimates with a difference of 59 individuals, with POPAN producing the lower estimate (311) and MLE the larger estimate (370). The upper and lower confidence intervals of both models overlap at 333–373 individuals. The size of confidence intervals varied but the MLE models have smaller CI's than POPAN.

POPAN was selected for its suitability for open populations and its widely accepted use for modeling open population demographics. In a simulation study by Gupta et al. (2017), POPAN's ability to model population size for a wide-ranging species was investigated. Although the modeling technique was found to underestimate population size, bias levels were small. The least biased estimates occurred when there was a random trap arrangement, high trap density and high population density. In this study, the "trap arrangement" was non-random transects with an opposing zig-zag layout which remained constant and uniform throughout the study and had an average density of 0.8 transects per km$^2$. Population density estimated from the POPAN abundance estimate was an average of 2.4 IP bottlenose dolphins per km$^2$, which is relatively high compared with populations in similar sized study areas (Möller et al., 2002, Nicholson et al., 2012, Smith et al., 2013, Brown et al., 2016, Raudino et al., 2018). POPAN estimated capture probabilities at an average of 0.44 (0.33 – 0.55) with less than 50% of individuals likely to be recaptured in each sampling period suggesting individual heterogeneity and transience, violating the model assumption that individuals were equally likely to be captured. Goodness of fit testing supported this [Test 3.SR, Test 3. SM and global test (Test 2 + 3)]. Models were averaged to account for model selection uncertainty and AICc values were adjusted after the variance inflation factor indicated over dispersion of the data, suggesting that this model might have underestimated population size and may not be the most appropriate for estimating abundance of this population due to the high level of transience and non-resident individuals.

The MLE transient model which was primarily developed for dolphins, was selected in this study for its ability to account for individual heterogeneity in populations in which there is a spatial overlap of resident and non-resident individuals (Conn et al., 2011). The model assumes a strict dichotomy of two groups: residents and transients, which may not be appropriate for all study populations, but was deemed a suitable assumption for this population due to the high proportion of individuals only seen once. Although the model employs a “one sample availability”, Conn et al. (2011) simulated the effect of violations in the model assumptions if transients were to remain in the study area longer than one sampling period. If transients remained in the study area and were sampled on more than one occasion, resident abundance estimates exhibited an overall positive bias of less than 5%. In my study, 18% of individuals in the non-resident cluster were sampled more than once, which I acknowledge may have created some bias in abundance estimates. However, the MLE model generates α which is the probability that a randomly encountered individual is a resident. This value was estimated at 38%, which is very similar to the proportion of residents produced in my agglomerative hierarchical clustering (AHC) analysis (42%). As it is not higher than what was estimated in my site fidelity analysis and due to the high proportion of individuals only seen once (40%), I assume that overestimation of the resident population size has not occurred. Although goodness of fit testing has not been developed for this model I am confident in its estimates of population size.

### *2.5.5 Conservation implications*

Determining and monitoring the effect of coastal development on inshore dolphins is challenging in great part because of the lack of adequate baseline studies. This study provides the first demographic assessment of IP bottlenose dolphins inhabiting the coastal waters of the NWC, within the Ningaloo Coast World Heritage Area (NCWHA), NMP and Exmouth Gulf. Results should aid wildlife agencies and future impact studies by serving as a point of reference to compare and evaluate changes over time and develop appropriate management and mitigation strategies.

The results of this chapter show that a large population inhabits the waters of the NWC and highlights the importance of the NWC for IP bottlenose dolphins. As large populations of megafauna are becoming increasingly rare in coastal habitats that are subject to increasing human activities (Jackson et al., 2001), this population is of high conservation value. Marine Parks are often established in order to protect vulnerable species and ecosystems, to conserve biodiversity and to minimise the risk of extinction (Holt, 2009). The NMP offers a regulatory framework for conservation and manages human activities (e.g., fishing) that are recognised as potential threats to the species inhabiting these waters (DoEH, 2002). Once outside the marine park boundaries, individuals are at risk from all the threats the established park aims to protect them from (Holt, 2009, Hartel et al., 2015). The low site fidelity to the NWC indicates that individuals of the IP bottlenose dolphin rely on and use habitat outside the 130 km$^2$ study area and more importantly, move from the boundaries of the protected NMP and NCWHA and into the unprotected waters of Exmouth Gulf or other adjacent waters. Future management plans for the NMP and NCWHA should consider extending these boundaries so that the Exmouth Gulf is included. Future surveys should be completed in the Gulf to determine the true importance of this area to the population.

# 3 CHAPTER 3: DISTRIBUTION AND HABITAT PREFERENCES OF INDO-PACIFIC BOTTLENOSE DOLPHINS (*TURSIOPS ADUNCUS*) INHABITING COASTAL WATERS WITH MIXED LEVELS OF PROTECTION

## 3.1 Abstract

Assessments of species distributions are crucial for informing conservation and management actions. In this study, I used ensemble modelling to explain the distribution of Near Threatened Indo-Pacific (IP) bottlenose dolphins (*Tursiops aduncus*) inhabiting coastal waters at the North West Cape (NWC), Western Australia (WA), an area encompassing a marine protected area and adjacent unprotected coastal waters. Analyses used boat-based survey data collected from 2013 to 2015 and 2018 to 2019. Overall, the distribution of IP bottlenose dolphins was best explained by distance to coast (up to 2000 m) and distance to boat ramp (up to 7000 m). Areas of high probability of occurrence for dolphins extended from the tip and down the eastern side of the NWC and overlapped with designated Sanctuary Zones as well as waters beyond the boundaries of the Ningaloo Marine Park (NMP). Distribution and habitat preferences varied slightly with season. In autumn, dolphin distribution was best explained by distance to coast and water depth with a higher likelihood of observing dolphins 1000 to 2000 m from the coast and in water depths of 7-10 m deep. During winter months, distance to coast (1000 to 2000 m) and sea surface temperature (21.5°C to 23.5°C) were the most important explanatory variables, with presence in coastal lagoons to the west of the NWC more likely than other seasons. During spring, areas of moderate to high probability of dolphin occurrence were mainly located outside the NMP. However, inside the NMP boundaries, Sanctuary Zones were considered likely to contain dolphins with marine park zone (Sanctuary and outside the marine park) and water depth (waters 7 – 13 m deep) best explaining dolphin distribution. This study highlights the importance of inshore areas of the North West Cape, for Indo-Pacific bottlenose dolphins and the potential vulnerability of this species to increasing and cumulative anthropogenic

stressors associated with these areas. Results of this study will aid managers with future decision-making and spatial conservation prioritisation, allowing for effective management of this Near Threatened species.

## 3.2 Introduction

Coastal marine ecosystems and their associated habitats are among the most productive and are considered to be of great ecological importance and societal value (Costanza et al., 1997). These ecosystems, their habitats and the species that reside within them are under ever-increasing pressure from a variety of anthropogenic activities such as overfishing, habitat degradation, pollution, urbanisation, disturbance from vessels and climate change (Lotze et al., 2006, Diaz and Rosenberg, 2008, Davidson et al., 2012, Halpern et al., 2007, Crain et al., 2009b, Brown and McLachlan, 2002). Coastal habitats are important habitat for marine megafauna, particularly marine mammals, which have been identified as both indicator and umbrella species with their presence often used as a potential signal of ecosystem health (Bossart, 2011, Moore, 2008). Marine mammal conservation actions are likely to benefit the protection of other organisms and the wider ecosystem because of top-down and bottom-up ecosystem processes and the roles marine mammals play as top predators (Paine, 1969, Paine, 1995, Roberge and Angelstam, 2004, Roman and McCarthy, 2010). In addition, marine mammals are important culturally and economically, with marine ecotourism benefits spanning from increased education and appreciation of the marine environment to sustaining local economies (Corkeron, 2004, Muloin, 1998, O'Connor et al., 2009, Stamation et al., 2007).

Marine Protected Areas (MPAs) have been defined as “a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Dudley, 2008, Day et al., 2012). MPAs have been identified as a tool to manage anthropogenic threats and safeguard the biodiversity of coastal ecosystems (Halpern et al., 2010, Tardin et al., 2020). Yet, despite many studies demonstrating positive effects of MPAs, this is not always the case (Lester et al., 2009). There is strong evidence that MPAs are only effective conservation tools when the boundaries encompass areas that are biologically and ecologically relevant to populations and include areas where the conservation feature is exposed to anthropogenic threats, particularly for highly mobile, wide-ranging species such as marine mammals (Hooker et al., 1999, Hooker and Gerber, 2004, Wilson et al., 2004, Hartel et al., 2015, Lambert et al., 2017, Dwyer et al., 2020). Without the inclusion of adequate spatial and biological information, habitats can be over- or under-protected, with the latter compromising the conservation and management of important marine species and ecosystems (Hartel et al., 2015, Gregr et al., 2013, Guisan et al., 2013, Davidson et al., 2012). Thus, information on the spatial distribution of marine mammals and the physical and biological environmental factors influencing such distribution is essential to inform and evaluate conservation and management decisions and future environmental impacts (Zanardo et al., 2017, Passadore et al., 2018a, Hunt, 2018).

A key tool for identifying and predicting the relationship between species occurrence and the environmental and anthropogenic conditions associated with their habitat is species distribution modelling (SDMs) (Elith and Leathwick, 2009, Franklin, 2010, Guisan and Zimmermann, 2000). SDMs examine the relationship between the distribution (e.g. occurrence) of a species and the environmental variables that influence habitat selection, and have been used widely on terrestrial and marine fauna (Rickbeil et al., 2014, Zacarias and Loyola, 2018, James et al., 2017, MacLeod et al., 2008), including dolphins (Passadore et al., 2018a, Hunt, 2018, Vargas-Fonesca et al., 2018, Sprogis et al., 2018a, Zanardo et al., 2017, Dwyer et al., 2020, Tardin et al., 2020). Further, SDMs can help to understand which areas are used more often by animals and the environmental features that are correlated with species distributions (Marini et al., 2015, Vargas-Fonesca et al., 2018, Garraffo et al., 2011). In turn, such information can be useful for developing management practices to improve species conservation outcomes.

Indo-Pacific (IP) Bottlenose dolphins (*Tursiops aduncus*), recently re-listed as Near Threatened by the IUCN (Braulik et al., 2019), are long lived, slow to sexually mature, display a high degree of parental care to offspring and inhabit shallow, coastal habitats (Mann et al., 2000, Hammond et al., 2012, Wang and Chu Yang, 2009, Braulik et al., 2019). Increasing urbanisation and human use of coastal areas exposes IP bottlenose dolphins to repeated and cumulative stressors that have the potential to disrupt and displace individuals (Lusseau and Higham, 2004, Smith et al., 2016, Bejder et al., 2006). Therefore, identifying habitat preferences and areas of high probability of occurrence is a key priority for effectively conserving IP bottlenose dolphins, as well as other coastal dolphin populations.

Marine habitats are in general, spatially heterogeneous and the distribution of marine mammals such as bottlenose dolphins, has been linked to a number of biotic (e.g. habitat type, prey distribution, interspecific competition), abiotic (e.g. sea surface temperature, bathymetry, distance to coast), and anthropogenic variables (e.g.

fishing activity, boat traffic and MPAs) (Ingram and Rogan, 2002, Bearzi et al., 2008, Passadore et al., 2018a, Bilgmann et al., 2019, Inoue et al., 2017, Hartel et al., 2015, Vargas-Fonesca et al., 2018, Sprogis et al., 2018a, La Manna et al., 2010, Zanardo et al., 2017). The range of variables driving bottlenose dolphin presence around the world is indicative of the broad behavioural and ecological plasticity of bottlenose dolphins; highlighting the need to understand and manage individual populations as discrete units (Bilgmann et al., 2019, Connor et al., 2000).

Coastal waters of the North West Cape (NWC) encompassing the northern section of the Ningaloo Marine Park (NMP) and Exmouth Gulf in Western Australia (Figure 3.1), are home to a relatively large population of 311 to 370 IP bottlenose dolphins (Haughey et al., 2020). The population is composed of 141 individuals who display moderate levels of site fidelity to the NWC and a slightly larger number of individuals (229) who display low site fidelity, and range beyond the NWC and the boundaries of the NMP. The NMP is a multi-use MPA managed under a zoning approach primarily located to the west of the NWC falling within the Ningaloo Coast World Heritage Area (NCWHA) (CALM and MPRA, 2005, DoEWHA, 2010, UNESCO., 2011). The NMP was established in 1987 after the conservation significance of the Ningaloo Reef; Australia’s longest fringing reef, was recognised and in 2004 the boundaries were extended to include the northern extremity of the reef (CALM and MPRA, 2005). IP bottlenose dolphins have been recognised to be of conservation significance and key ecological value to the marine park, with management actions targeting the management of tourist presence, dolphin research, understanding impacts of nature-based tourism and maintaining records of entanglements and strandings in order to meet the long-term target of no loss of dolphin diversity as a result of human activity in the NMP(CALM and MPRA, 2005). Yet, designation of marine park boundaries and management zones were determined prior to establishing knowledge on the range and habitat requirements of this IP bottlenose dolphin population. On the eastern side of the NWC and outside the NMP lies the Exmouth Gulf, which is recognised as an important ecosystem containing globally significant features and supporting high biodiversity, yet remains unprotected (Fitzpatrick et al., 2019). The Exmouth Gulf has not received as much attention as the NMP and many knowledge gaps of the marine ecosystem exist, posing problems for its overall conservation and management (Fitzpatrick et al., 2019).

Coastal development and anthropogenic pressures overlapping with the distribution of IP bottlenose dolphins at the NWC have preceded baseline ecological information and an accurate assessment of these threats. A broad scale dolphin SDM, using opportunistic sightings from a dugong aerial survey, indicated that waters north-east of the NWC and within the Exmouth Gulf, were highly likely to contain IP bottlenose dolphins, in water depths of 10-25 m, particularly around the 20 m depth contour and in steeper seafloor gradients (Hanf et al., in review) . Seasonally, sea surface temperature (SST) influenced dolphin distribution with a positive response in warmer waters and a negative response when waters are cooler (Hanf et al., in review). Given the high number of IP bottlenose dolphins using the coastal waters of the NWC and the varying levels of marine protection in the area, establishing baseline ecological data for the species, including distribution, is a critical next step towards their effective conservation and management.

Here I used dolphin sightings from boat-based surveys and ensemble species distribution modelling to (1) identify the biotic, abiotic and anthropogenic variables influencing distribution and habitat selection and (2) identify the distribution patterns and areas of high probability of occurrence of IP bottlenose dolphins at the NWC. My results improve the understanding of IP bottlenose dolphin spatial ecology at the NWC and highlight key areas for spatial conservation prioritisation.

## 3.3 Methods

### *3.3.1 Study site*

The study area encompassed the coastal waters surrounding the North West Cape (NWC) in north-western Australia from the Exmouth Marina in the Exmouth Gulf, around the tip of the NWC and south to Mangrove Bay (Figure 3.1). Approximately 150 km$^2$ of the 237 km$^2$ area where IP bottlenose dolphin occurrence was modelled falls within the Ningaloo Marine Park (NMP), while the remaining 87 km$^2$ falls within the unprotected Exmouth Gulf. Boat-based surveys for Indo-Pacific (IP) bottlenose dolphins in this study took place both inside and outside the boundary of the NMP (Figure 3.1).

The western side of the NWC features a mostly sandy substrate and a fringing coral reef system (CALM and MPRA, 2005, Cassata and Collins, 2008). The fringing (sub-tidal) reef system is separated from the coast by shallow sandy lagoons and coral communities (i.e. less than 5 m deep) (Collins et al., 2003). After the subtidal ocean edge of the reef, the continental shelf drops off quickly, exposing the reef to considerable wave action (e.g. swell height >2 m) (Cassata and Collins, 2008, CALM and MPRA, 2005, Collins et al., 2003).

On the Eastern side of the NWC is the Exmouth Gulf, a large sub-tropical inverse estuary which reaches depths of 21 m, with a mean depth of 10-12 m (Fitzpatrick et al., 2019, Ayukai and Miller, 1998, Brunskill et al., 2001). The Gulf is comprised of mostly subtidal sandy bottoms and limestone reefs, but also a large arid zone mangrove ecosystem (Lyne et al., 2006, Fitzpatrick et al., 2019, Brunskill et al., 2001, Twiggs and Collins, 2010).

The NMP is managed using a zoning system including Sanctuary, Recreational, Special Purpose (Shore-Based) and General Use Zones. Sanctuary Zones, also termed ‘no take zones’, are areas where extractive activities such as fishing are prohibited; Recreational Zones allow recreational fishing; and General Use Zones permit both recreational and sustainable commercial activities (CALM and MPRA, 2005). In the Special Purpose (Shore-Based) Zones situated on the coastline adjacent to the Point Murat, Lighthouse Bay and Jurabi Sanctuary Zones (Figure 3.1), recreational line fishing from the beach is permitted. In General Use Zones, sustainable commercial activities are permitted in addition to recreational fishing (CALM and MPRA, 2005). In the area zoned as Naval Waters, no fishing is permitted within 400 m of the pier and boats are not permitted to stop or anchor in these waters (DoT., 2019). Outside the NMP boundaries, there is no restriction on the recreational or commercial activities permitted.

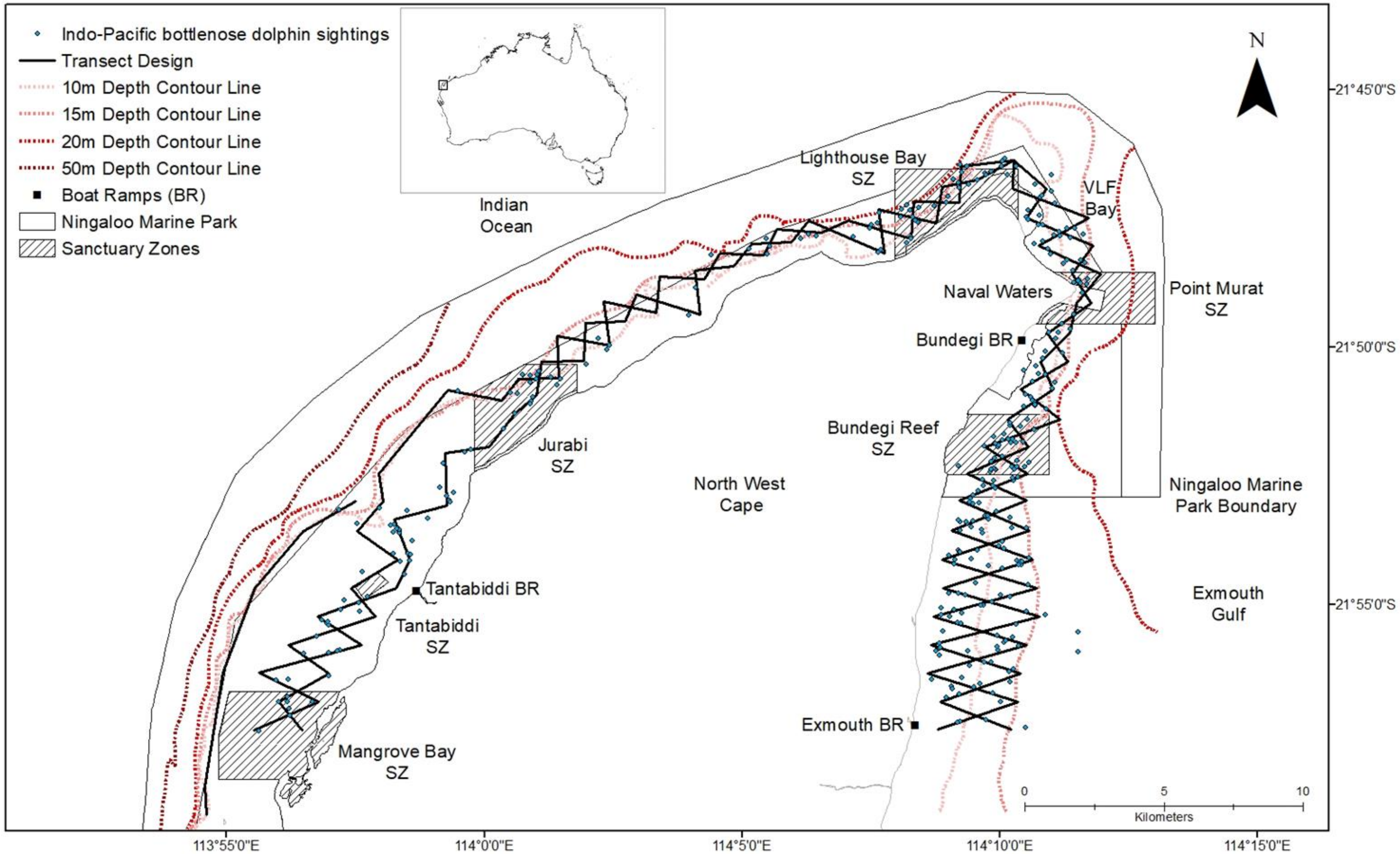


**Figure 3.1:** Map of the North West Cape study site in Western Australia, including transect layout and Indo-Pacific bottlenose dolphin sightings (n = 323) encountered between 2013-2015 and 2018-2019.

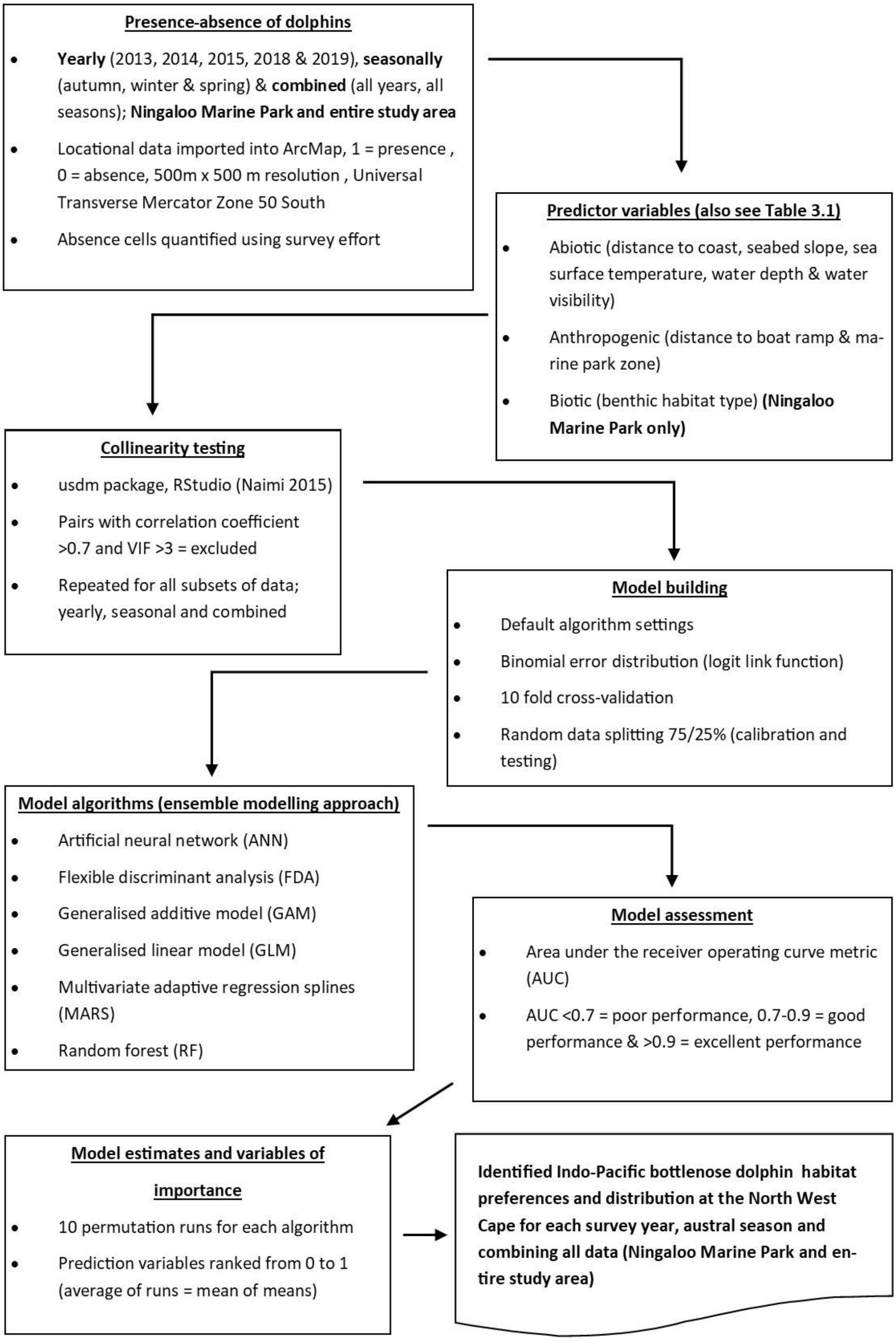
### **3.3.2** *Data collection*

Boat-based surveys searching for IP bottlenose dolphins were conducted onboard a 5.6 m research vessel during the hours of 0700 to 1800 from May to October in 2013, April to October in 2014, May to October in 2015 and April to September in both 2018 and 2019. Sampling periods spanned the austral seasons of Autumn (March - May), Winter (June - August) and Spring (September – November). Sampling was not conducted during summer and early autumn months (December – February, and March respectively) due to strong wind conditions which produce unsuitable sighting conditions for coastal dolphins, in addition to extreme temperatures and higher risk of tropical cyclones. Surveys were conducted in favourable sighting conditions (i.e. Beaufort Sea State of ≤3 and no rain) and followed a systematic line transect layout (i.e. 2 x 93 km opposing zig-zag lines and 1 x 13 km single line; Figure 3.1) covering a range of water depths, benthic habitats and marine park zones within the study area.

A crew of three to five (mode = four) observers searched for dolphins forward of the vessel's beam using a combination of the naked eye and 7 x 50 zoom binoculars. When a school of dolphins was sighted, search effort was suspended and dolphins were approached to within 5 - 30 m to record a GPS location, the predominant school behaviour (i.e. behavioural state in which more than 50% of the animals in the school are involved; Mann, 1999; see Chapter 4)), conduct photo-identification and collect environmental data (i.e. water depth, sea surface temperature and water visibility). In addition, environmental data were collected *in situ* at the beginning and end point of transects, and at various random locations throughout the survey area. Water depth was recorded using the research vessel's depth sounder, sea surface temperature (SST) was recorded using a handheld multiparameter probe, and water visibility was measured using a secchi disk. Data used to derive other predictor variables were derived from available shapefiles (see *3.3.3.2 Predictor variables*).

### *3.3.3 Data analysis*

Analysis of data to identify IP bottlenose dolphin habitat preferences and space use patterns at the NWC involved a series of steps; (1)mapping the location (presence-absence) of dolphin sightings onto a 500 by 500m grid resolution., (2) selecting predictor variables, (3) collinearity testing of predictor variables, (4) model algorithm selection, (5) model building, (6) model assessment and (7) model estimation (i.e. determining variable importance). The procedures followed to create spatial layers of response (dolphin presence-absence) and predictor variables at a 500 x 500 m grid resolution are summarised in Figure 3.2 and described in detail in sections 3.3.3.1 and 3.3.3.2. . SDMs were run per year of survey, per austral season and combining all data for both the NMP portion of the study area and the entire study area (see Appendix S2.2 for the yearly and NMP SDMs). All SDM analysis is also explained in S2.1 (Appendix 2 of this thesis) following the Overview, Data, Model, Assessment and Prediction (ODMAP) protocol recommended by Zurell et al. (2020).



**Presence-absence of dolphins**

- **Yearly** (2013, 2014, 2015, 2018 & 2019), **seasonally** (autumn, winter & spring) & **combined** (all years, all seasons); **Ningaloo Marine Park and entire study area**
- Locational data imported into ArcMap, 1 = presence , 0 = absence, 500m x 500 m resolution , Universal Transverse Mercator Zone 50 South
- Absence cells quantified using survey effort

**Predictor variables (also see Table 3.1)**

- Abiotic (distance to coast, seabed slope, sea surface temperature, water depth & water visibility)
- Anthropogenic (distance to boat ramp & marine park zone)
- Biotic (benthic habitat type) **(Ningaloo Marine Park only)**

**Collinearity testing**

- usdm package, RStudio (Naimi 2015)
- Pairs with correlation coefficient >0.7 and VIF >3 = excluded
- Repeated for all subsets of data; yearly, seasonal and combined

**Model building**

- Default algorithm settings
- Binomial error distribution (logit link function)
- 10 fold cross-validation
- Random data splitting 75/25% (calibration and testing)

**Model algorithms (ensemble modelling approach)**

- Artificial neural network (ANN)
- Flexible discriminant analysis (FDA)
- Generalised additive model (GAM)
- Generalised linear model (GLM)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)

**Model assessment**

- Area under the receiver operating curve metric (AUC)
- AUC <0.7 = poor performance, 0.7-0.9 = good performance & >0.9 = excellent performance

**Model estimates and variables of importance**

- 10 permutation runs for each algorithm
- Prediction variables ranked from 0 to 1 (average of runs = mean of means)

**Identified Indo-Pacific bottlenose dolphin habitat preferences and distribution at the North West Cape for each survey year, austral season and combining all data (Ningaloo Marine Park and entire study area)**

**Figure 3.2:** Flowchart summarising the data analysis process used for ensemble modelling of Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) habitat preferences and distribution at the North West Cape, Western Australia.

#### *3.3.3.1 Presence-absence of dolphins*

ArcMap version 10.7 (ESRI) was used to create spatial layers of response (dolphin presence-absence) and predictor variables at a 500 x 500 m grid resolution (see Table 3.1 and Figure 3.2). This resolution ensured sufficient detail of each variable throughout the study area. All spatial layers were projected to Universal Transverse Mercator zone 50 South, based on the WGS 1984 datum. The GPS locations of dolphins sighted whilst on transect and survey tracks were imported into ArcMap to create a presence-absence layer of dolphin presence per grid cell (1 indicating dolphin presence and 0 indicating dolphin absence), while accounting for survey effort (summarised in Figure 3.2). To ensure independence of data points (since bottlenose dolphins exhibit flexible grouping patterns; Wells et al., 1987), for each sighting only the location where the initial group members were first encountered was included in analysis.

In order to reduce false absences (i.e. determining an absent cell when individuals may in fact occur in that area), absence cells were defined based on areas which had the highest survey effort (Phillips et al., 2009) (summarised in Figure 3.2). Survey effort was quantified using the total area of ‘on-effort’ survey tracks within each 500 x 500 m grid cell. A 250 m buffer area either side of each transect line was added, which was considered to be the average distance from the vessel that dolphins could reliably be observed under a variety of sea conditions (Zanardo et al., 2017, Hunt, 2018). Grid cells were then ranked and cells containing no dolphin presence and values of survey effort higher than the mean were considered as absence cells (Zanardo et al., 2017, Hunt, 2018, Passadore et al., 2018a).

#### *3.3.3.2 Predictor variables*

Predictor variables used to model IP bottlenose dolphin distribution and occurrence were classified as: abiotic (i.e. water depth, slope, sea surface temperature (SST), distance to coast and water visibility), biotic (i.e. habitat type, for NMP SDM only, see S2.2 in Appendix 2 of this thesis) and anthropogenic (i.e. distance to boat ramp and marine park zone) (Table 3.1). Predictor variables used in this study were selected because they are known or have been suggested to affect the presence of bottlenose dolphins or their prey, with some variables acting as proxies for prey distribution (i.e. SST), predation risk (i.e. water visibility), and areas of high human use and anthropogenic disturbance (i.e. distance to boat ramp and marine park zone) (Ingram and Rogan, 2002, Sprogis et al., 2018a, Passadore et al., 2018a, Zanardo et al., 2017, Heithaus and Dill, 2002).

It was chosen to include covariate data collected *in situ* while surveying for IP bottlenose dolphins in the modelling process for a number of reasons. Firstly, available remote sensing data did not cover the entire study area, excluding waters close to the coast. Secondly, the resolution of available remote sensing data is not suitable for the fine-scale resolution, 500m x 500m grid cell size, used in this study. Thirdly, as the covariate data was collected during the time of dolphin surveys it is considered the most accurate environmental data for that period. Benthic habitat data only exist for the NMP portion of the study area (for NMP boundaries, see Figure 3.1). This data was derived from a broad scale benthic habitat study of the NMP using remotely sensed imagery and aerial photographs (DPaW., 2006, Lucieer et al., 2017, Bancroft and Sheridan, 2000).

A shape file of marine park zoning data was obtained from the Western Australian Government Department of Biodiversity, Conservation and Attractions (DPaW. and DoF., 2014) in order to evaluate the relevance of the marine park zoning for the distribution and space use of IP bottlenose dolphins within the study area.

**Table 3.1:** List of predictor variables used in species distribution modelling (SDM) of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the coastal waters of the North West Cape (NWC), their associated data source and how they were derived in ArcMap. * indicates the variable was only included in Ningaloo Marine Park SDMs. Spatial resolution for each variable is 500 x 500m.

| Type | Name | Variable abbreviation | Data Source |
|---|---|---|---|
| Abiotic | Distance to coast | N/A | Derived using the Euclidean distance tool (Spatial Analyst toolbox). |
| Abiotic | Slope | Slope | Derived using the Slope tool and is measured in decimal degrees (Spatial Analyst toolbox). |
| Abiotic | Sea surface temperature | SST | Derived from *in situ* measurements of SST. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size)(Spatial analyst toolbox). |
| Abiotic | Water depth | Depth | Derived from *in situ* measurements of depth. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst toolbox). |
| Abiotic | Water visibility | N/A | Derived from *in situ* measurements of water visibility using a secchi disk and calculated as a proportion of the total depth.<br>Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst Toolbox). |
| Biotic | Benthic habitat type | Habitat | Derived from a broad scale benthic habitat study of the NMP (DPaW., 2006, Lucieer et al., 2017, Bancroft and Sheridan, 2000). Data was only available for the Ningaloo Marine Park portion of the study area (Figure 1). Habitat type was classified as either 1=mobile sand, 2=mangroves, 3=bare reef (intertidal), 4=coral reef (intertidal), 5=bare reef (subtidal), 6=macro algae (subtidal), 7=coral reef (subtidal), 8=saltmarsh and 10=pelagic (No habitat type associated with a value of 9 (mudflat) is present in this section of the NMP). For habitat type definitions, see S2.3 (Appendix 2). Each grid cell was assigned a variable according to habitat type using the polygon to raster tool. |
| Anthropogenic | Distance to boat ramp | N/A | Exmouth, Bundegi and Tantabiddi boat ramps are established vessel launch sites in the study area. Derived using the Cost distance tool (Spatial Analyst toolbox) and the coast shapefile as the cost surface |
| Anthropogenic | Marine park zone | NMP Zone | A NMP zoning shape file which shows the zone boundaries was obtained from the Western Australian Government Department of Biodiversity, Conservation and Attractions service. Zoning included the categories: |

| | | | |
|---|---|---|---|
| | | | 1=General Use, 2=Recreational, 3=Sanctuary, 4= Special Purpose, 5 = Naval Waters, 6 = outside the NMP (DPaW. and DoF., 2014). Each grid cell was assigned a variable according to MP zone using the polygon to raster tool. |

#### *3.3.3.3 Exploratory analyses*

Before running the SDMs, I tested for collinearity between continuous numerical explanatory variables using stepwise procedures within the usdm package in RStudio (Naimi, 2015). Variance Inflation Factors (VIF) were calculated for all variables. Variable pairs with a maximum linear correlation greater than the threshold (0.7) were identified using ‘vifcor’ and the variable with the highest variance inflation factor (VIF, threshold = 3) was excluded using ‘vifstep’ (Zuur et al., 2010). These procedures were repeated until no variable remained with a correlation coefficient greater than 0.7 nor a VIF greater than the threshold remained (Naimi et al., 2014) (summarised in Figure 3.2).

Combining data can strengthen the estimates of SDMs, however it is important to consider temporal variability, particularly in highly dynamic environments and in a changing climate as changes in oceanographic processes can affect the spatial distribution of prey and therefore the presence-absence of highly mobile species, such as dolphins (Fernandez et al., 2017, Mannocci et al., 2017). Additionally, benthic habitat type has been shown to influence habitat selection and space use of IP bottlenose dolphins (Sprogis et al., 2018a, Zanardo et al., 2017, Koper et al., 2016), however spatial data on benthic habitat type is only available for a subset of the study area (the NMP portion, Figure 3.1). Therefore, a series of preliminary SDMs were run to investigate aggregating all temporal data and to determine the importance of benthic habitat type as a predictor of IP bottlenose dolphin distribution within the NMP portion of the study area (see S2.2 in Appendix 2 of this thesis). The results of yearly SDMs indicated that the spatial distribution and areas of high probability of IP bottlenose dolphin occurrence in the NWC remained similar across years. SDMs within the NMP portion of the study area indicated that benthic habitat type was not an important variable influencing IP bottlenose dolphin distribution. Thus, SDMs presented in this chapter combined all five years of survey data to examine seasonal and overall habitat preferences and space use patterns of IP bottlenose dolphins within the entire study area.

#### *3.3.3.4 Selection of model algorithms and ensemble modelling approach*

Multiple modelling techniques have been developed to model species distribution, but the best performing models vary, with no model consistently superior in performance across studies, species and regions (Araujo and New, 2007, Elith and Graham, 2009, Marmion et al., 2009). Ensemble modelling has become increasingly popular, combining multiple single model predictions to reduce bias of single model approaches and to produce more robust estimates of species distributions through a ‘consensus’ approach (Araujo and New, 2007, Thuiller et al., 2009, Hao et al., 2019). Ensemble modelling has been successfully applied to marine taxa (Riul et al., 2013, Pikesley et al., 2015, Alabia et al., 2016, Abrahms et al., 2019) including coastal dolphins (Hanf et al., in review, Zanardo et al., 2017, Hunt et al., 2020, Passadore et al., 2018a). Therefore, to model NWC IP bottlenose dolphin distribution in relation to the chosen predictor variables, I used an ensemble modelling approach, using the BioMod2 package in RStudio (Thuiller et al., 2009). This method combined results from seven different presence-absence modelling algorithms; artificial neural network (ANN) (Ripley, 1996), flexible discriminant analysis (FDA) (Hastie et al., 1994), generalised additive model (GAM) (Hastie and Tibshirani, 1990), generalised boosted model (GBM) (Friedman et al., 2000), generalised linear model (GLM) (McCullagh and Nelder, 1989), multivariate adaptive regression splines (MARS) (Friedman, 1991) and random forest (RF) (Breiman, 2001) (summarised in Figure 3.2).

#### *3.3.3.5 3.3.3.5 Model building*

The parameters used with each model algorithm in the Biomod2 package are listed in S3.3 in Appendix 3 of this thesis. SDMs were built using a binomial error distribution with logit as the link function. I implemented a 10-fold cross-validation method for each SDM and a random data splitting procedure of 75/25% for model calibration and testing (Thuiller et al., 2009) (summarised in Figure 3.2).

#### 3.3.3.6 3.3.3.6 Model assessment

SDMs have the potential to produce false positives (i.e. predict species occurrence in areas where the species does not occur) and false negatives (i.e. fail to predict species occurrence in areas where the species does occur) (Guisan and Thuiller, 2005). The area under the receiver operating characteristic curve (AUC) metric was used to evaluate SDM predictive performance (Fielding and Bell, 1997). Values of AUC range from 0 to 1; with values >0.5 indicating that the model predictions perform better than random, whereas values <0.5 indicates that the model predictions are no better than what would be expected by chance. In general, AUC values of 0.5–0.7 are considered low and represent poor model performance, values of 0.7–0.9 are considered moderate to good, and values above 0.9 represent excellent model performance (Peterson et al., 2011, Fielding and Bell, 1997) (summarised in Figure 3.2).

#### *3.3.3.7 3.3.3.7 Model estimates and variables of importance*

The importance of explanatory variables was calculated using a 10-permutation run randomisation procedure within BioMod2 (Thuiller et al., 2009). This procedure allows for a direct comparison between model algorithms and calculates the Pearson’s correlation between the standard predictions and predictions where one variable has been randomly permutated. High correlation (i.e. little difference between the two predictions) indicates that the variable is not important in the model, and a low correlation indicates that the variable is important. Variables are then ranked from 0 to 1 according to the mean correlation coefficient, with the variable with the highest ranking the most influential and the lowest, the least influential (Thuiller et al., 2009) (summarised in Figure 3.2).

## 3.4 Results

### *3.4.1 Survey effort and dolphin encounters*

Over the five years of study, a total of 723 hours of survey effort were completed (Table 3.2). Survey effort varied slightly between years and austral seasons due to variability in weather conditions. Overall, the highest survey effort and number of Indo-Pacific (IP) dolphin sightings occurred during the winter months (June-August). In total, 323 groups of IP bottlenose dolphins were encountered, with 70 seen in autumn, 184 in winter and 69 in spring. Overall, 227 (70%) of these groups were seen inside the Ningaloo Marine Park (NMP) section of the study area and the remaining 96 (30%) outside its boundaries (Figure 3.1).

**Table 3.2:** Summary of boat survey effort, number of dolphin schools encountered and number of 500 x 500 m grid cells with dolphin presences used to model Indo-Pacific bottlenose dolphin distribution per season across the entire North West Cape study area. Data collected between 2013 to 2015 and 2018 to 2019

| Time period | Survey effort (hours) | Number of dolphin schools sighted on effort | Probability of encounter per hour of survey effort (%) | Number of grid cells with presences |
|---|---|---|---|---|
| 2013 | 118.83 | 89 | 75 | 69 |
| 2014 | 158.95 | 83 | 52 | 69 |
| 2015 | 127.03 | 61 | 48 | 47 |
| 2018 | 154.67 | 39 | 25 | 35 |
| 2019 | 163.30 | 51 | 31 | 47 |
| Autumn (April - May) | 217.53 | 70 | 32 | 53 |
| Winter (June – August) | 356.15 | 184 | 52 | 123 |
| Spring (September - October) | 149.10 | 69 | 46 | 56 |
| Total | 722.78 | 323 | 45 | 175 |

### *3.4.2 Collinearity*

Correlation testing revealed collinearity between water visibility and depth, and high VIFs associated with water depth for the data used in the overall and seasonal models. All seasonal data revealed a high VIF associated with water depth (autumn, VIF = 4.00; winter; VIF = 5.72; and spring, VIF = 3.55) and in winter, a high correlation was identified between water depth and water visibility data (r= 0.82). For the overall dataset, collinearity was also identified between water visibility and water depth (r = 0.77) and a high VIF was associated with water depth (VIF = 5.34).

Due to the ecological importance of water depth reported in other coastal bottlenose dolphin habitat use studies (Heithaus and Dill, 2002, Heithaus and Dill, 2006, Sprogis et al., 2018a, Vargas-Fonesca et al., 2018, Zanardo et al., 2017, Passadore et al., 2018a), water visibility was dropped from the yearly species distribution models (SDMs) as an explanatory variable. Additional correlation testing (after the removal of water visibility), revealed no further collinearity within the seasonal and overall datasets. Thus, the remaining six explanatory variables were included in the overall and seasonal SDMs: distance to boat ramp, distance to coast, marine park zone, seabed slope, sea surface temperature (SST) and water depth.

### *3.4.3 Overall ensemble model of IP bottlenose dolphin distribution*

Due to the observed similarities in the location of modelled areas of high probability of dolphin occurrence and the explanatory variables explaining such distribution across years (see S2.2, S2.2.2 in Appendix 2 of this thesis), I pooled data (i.e. all 5 years combined) to examine the overall distribution and habitat preferences for IP bottlenose dolphins. After pooling all yearly data together, most of the single SDM algorithms performed well (range = 0.51 – 0.89, median = 0.81) (Figure 3.3). Any poor performing algorithm runs were excluded from the ensemble. The ensemble model outperformed all single SDMs with an AUC value of 0.92 indicating excellent model performance (Figure 3.3).

The ensemble model using all five years of study identified distance to coast (0.44) and distance to boat ramp (0.27) as the two most influential variables explaining IP bottlenose dolphin distribution (Table 3.3). All single SDM algorithms except GLM, suggested that distance to coast was the biggest driver of dolphin distribution. Also, GLM alone suggested marine park zone as an important variable explaining dolphin distribution (Table 3.3). Response curves indicated that the probability of dolphin occurrence was highest in areas 1000 – 2000 m from the coast, up to 7000 m from the nearest boat ramp and in marine park zone 6 (outside the NMP) (see S2.5 in Appendix 2 of this thesis).

The combined ensemble model showed a continuous stretch of moderate to high probability of occurrence for IP bottlenose dolphins from the tip and down the eastern side of the North West

Cape (NWC) (Figure 3.4). Also, IP bottlenose dolphins had a moderate probability of occurrence (0.61 to 0.80) in coastal lagoons on the west side of the NWC. Areas with high probability of dolphin occurrence (>0.81) were approximately 50:50 in and out of the NMP, with 51% of high probability of occurrence cells within the NMP and 49% outside these boundaries (Table 3.4). A small proportion (10%) of high probability of dolphin occurrence cells overlapped with three designated Sanctuary Zones; Lighthouse Bay, Point Murat and Bundegi Reef (Figure 3.4).

### *3.4.4 Seasonal ensemble models of IP bottlenose dolphin distribution*

Most of the single seasonal SDMs performed well, with the exception of several runs primarily from the ANN algorithm (autumn, range = 0.50 to 0.87, median = 0.73; winter, range = 0.40 to 0.84, median = 0.78 and; spring, range = 0.49 to 0.80, median = 0.68). These poor performing runs were excluded from the final ensembles. Ensemble models outperformed all single SDMs with AUC values above 0.9 indicating excellent model performance (autumn = 0.95, winter = 0.93 and spring = 0.93) (Figure 3.3).

The autumn ensemble model identified distance to coast (0.36) and water depth (0.30) as the two most important variables influencing IP bottlenose dolphin distribution (Table 3.3). All single SDM algorithms except GLM confirmed that distance to coast was the biggest driver of dolphin distribution. GLM also indicated marine park zone was an important variable explaining dolphin distribution (Table 3.3). Response curves indicated that the probability of dolphin occurrence was highest in areas 1000 – 2000 m from the coast, in water depths of 7 – 10 m and outside the NMP, in marine park zone 6 (see S2.6.1 in Appendix 2 of this thesis). In autumn, only two high probability of occurrence (>0.81) cells were modelled (one inside the NMP, in the Lighthouse Bay Sanctuary Zone and one outside the marine park boundaries) (Table 3.4). Moderate probability of occurrence (0.61 to 0.80) was predicted in the Mangrove Bay, Tantabiddi and Jurabi Sanctuary Zones on the west side of the NWC and almost continuously from the

Lighthouse Bay Sanctuary Zone at the tip of the NWC to the south-eastern boundary of the study area (Figure 3.4).

The winter ensemble model identified that the two most important variables influencing IP bottlenose dolphin distribution were distance to coast (0.36) and SST (0.24). All individual algorithms, except GLM supported the importance of either of these two variables, with GLM only identifying marine park zone as important (Table 3.3). Response curves indicated that the probability of dolphin occurrence was higher in areas 1000 – 2000 m from the coast, in water temperatures of 21.5°C – 23.5°C, in marine park zones 3, 5 and 6 (Sanctuary, Naval Waters and outside the NMP) (see Appendix 2 of this thesis, S2.6.2). During winter months, high probability of occurrence cells (>0.81) were heavily concentrated around the north-eastern tip of the NWC, with multiple cells extending from Bundegi Reef Sanctuary Zone to outside the NMP (Figure 3.4). In total, 75% of these high probability of occurrence cells fell inside the NMP and 25% outside the boundaries, with 30% within designated Sanctuary Zones (Table 3.4). Moderate probability of occurrence (0.61 to 0.80) was predicted in the coastal lagoons on the west side of the NWC and continuously from the Lighthouse Bay Sanctuary Zone to just north of the Exmouth boat ramp (Figure 4).

For spring, the ensemble model predicted the two most important variables influencing IP bottlenose dolphin distribution to be marine park zone (0.41) and water depth (0.28) (Table 3.3). However, the mean of means value indicated that distance to coast was more influential than water depth. All individual algorithms except ANN, agreed with the ensemble, supporting the importance of marine park zone and water depth, with ANN indicating distance to boat ramp (Table 3). Response curves indicated that the probability of dolphin occurrence was higher in water depths of 7-13 m and in marine park zones 3 and 6 (Sanctuary and outside the NMP) (see Appendix 2 of this thesis, S2.6.3). In spring, majority of the highest probability of occurrence (>0.81) cells were outside the marine park boundary, with 91% outside and 9% inside, in the Jurabi Sanctuary Zone (Figure 3.4 and Table 3.4). Moderate probability of occurrence (0.61 to 0.80) fell within the Mangrove Bay, Jurabi, Lighthouse Bay and Bundegi Reef Sanctuary Zones. During spring, a smaller section of the study area (compared to the other seasonal distribution maps), from Bundegi Reef Sanctuary zone to the south-eastern boundary of the study area had a consistent moderate probability of occurrence (Figure 3.4).

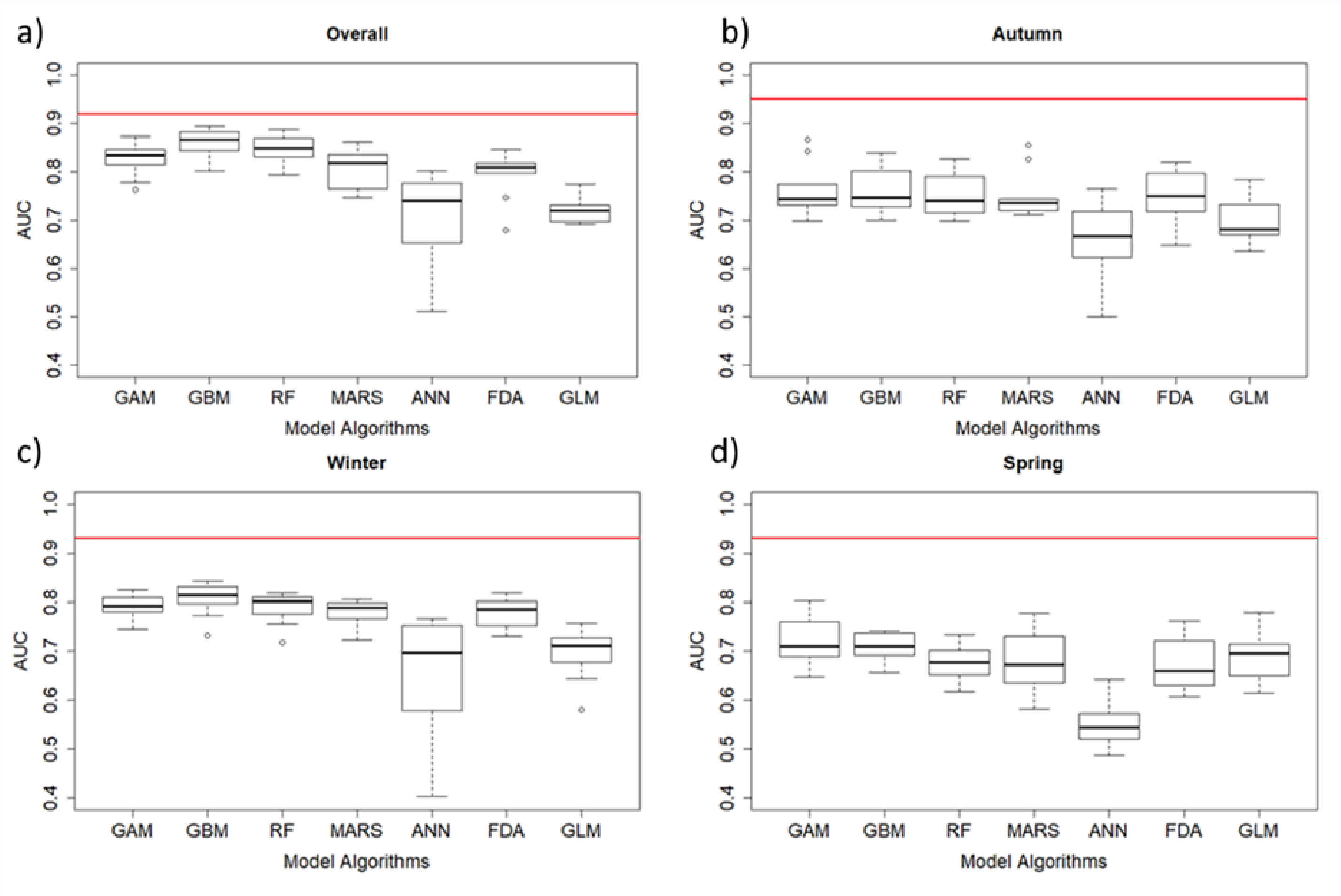
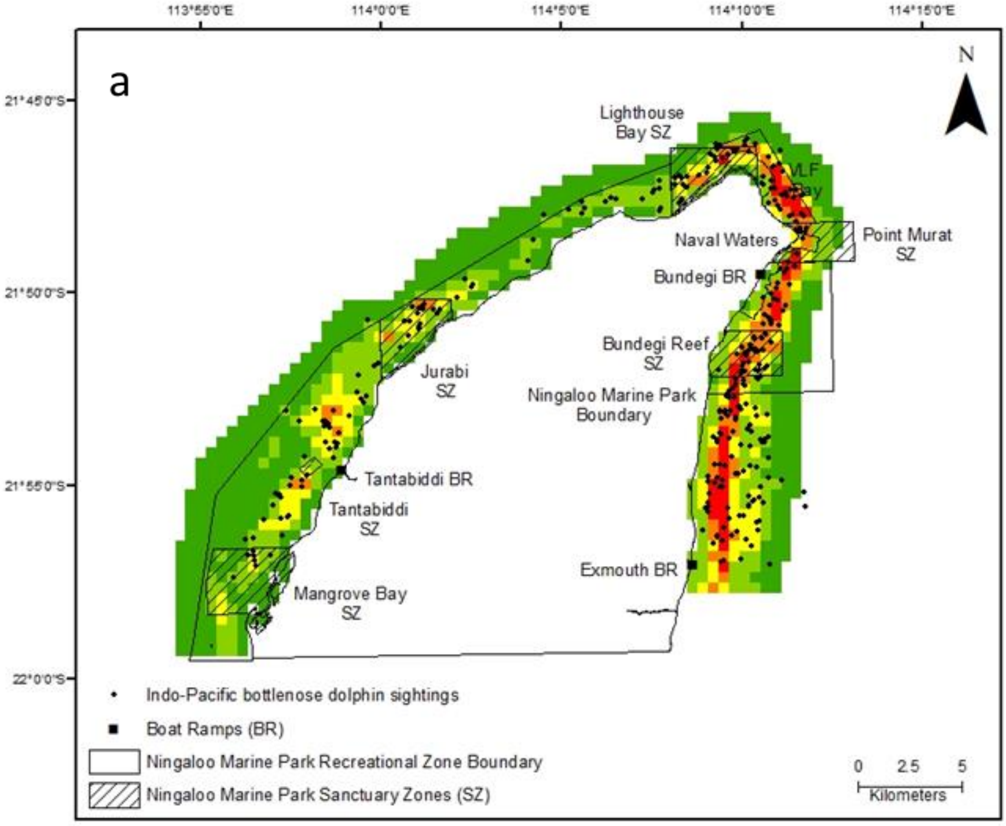


**Figure 3.3:** Performance of the overall (a) and seasonal (b-d) species distribution models of Indo-Pacific bottlenose dolphins at the North West Cape, Western Australia. Boxplots for the AUC (area under the curve of the receiver-operating characteristic) of the 10-cross validation runs of each modelling algorithm (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model). The red line shows the AUC of the ensemble model. Values of AUC ≥0.7 indicate that the model predictive performance is moderate to excellent.

**Table 3.3:** Importance of predictor variables used in the overall and seasonal species distribution models (SDMs) of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) at the North West Cape, Western Australia. Eight SDM algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), maximum entropy (MaxEnt), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as the ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| | **Model** | **Explanatory variables** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** |
| Overall | ANN$^{7}$ | 0.70 | **0.81** | 0.13 | 0.01 | 0.01 | 0.16 |
| | FDA$^{9}$ | 0.22 | **0.43** | 0.09 | 0.08 | 0.01 | 0.23 |
| | GAM$^{10}$ | 0.24 | **0.45** | 0.21 | 0.04 | 0.01 | 0.25 |
| | GBM$^{10}$ | 0.18 | **0.37** | 0.08 | 0.18 | 0.10 | 0.15 |
| | GLM$^{7}$ | 0.21 | 0.25 | **0.49** | 0.17 | 0.01 | 0.05 |
| | MARS$^{10}$ | 0.28 | **0.53** | 0.05 | 0.07 | 0.02 | 0.18 |
| | RF$^{10}$ | 0.15 | **0.32** | 0.07 | 0.17 | 0.16 | 0.17 |
| | Mean of means | **0.28** | **0.45** | 0.16 | 0.10 | 0.04 | 0.17 |
| | Ensemble | **0.27** | **0.44** | 0.17 | 0.10 | 0.04 | 0.16 |
| Autumn | ANN$^{3}$ | 0.71 | **0.82** | 0.03 | 0.00 | 0.01 | 0.24 |
| | FDA$^{8}$ | 0.08 | 0.16 | 0.29 | 0.00 | 0.17 | **0.67** |
| | GAM$^{9}$ | 0.16 | **0.38** | 0.32 | 0.03 | 0.21 | 0.34 |
| | GBM$^{10}$ | 0.10 | **0.27** | 0.17 | 0.12 | 0.16 | 0.30 |
| | GLM$^{4}$ | 0.14 | 0.21 | **0.57** | 0.15 | 0.04 | 0.00 |
| | MARS$^{10}$ | 0.15 | **0.42** | 0.10 | 0.02 | 0.21 | 0.35 |
| | RF$^{9}$ | 0.11 | 0.22 | 0.16 | 0.11 | 0.20 | **0.23** |
| | Mean of means | 0.21 | **0.35** | 0.24 | 0.06 | 0.14 | **0.30** |
| | Ensemble | 0.22 | **0.36** | 0.24 | 0.07 | 0.14 | **0.30** |
| Winter | ANN$^{5}$ | 0.76 | **0.77** | 0.10 | 0.00 | 0.02 | 0.15 |
| | FDA$^{10}$ | 0.17 | **0.42** | 0.21 | 0.08 | 0.28 | 0.16 |
| | GAM$^{10}$ | 0.11 | **0.35** | 0.26 | 0.05 | 0.21 | 0.22 |
| | GBM$^{10}$ | 0.08 | 0.22 | 0.04 | 0.23 | **0.41** | 0.14 |
| | GLM$^{7}$ | 0.15 | 0.08 | **0.53** | 0.14 | 0.14 | 0.01 |
| | MARS$^{10}$ | 0.19 | **0.41** | 0.08 | 0.06 | 0.24 | 0.16 |
| | RF$^{10}$ | 0.12 | 0.24 | 0.05 | 0.18 | **0.36** | 0.17 |
| | Mean of means | 0.22 | **0.36** | 0.18 | 0.11 | **0.24** | 0.14 |
| | Ensemble | 0.22 | **0.35** | 0.19 | 0.10 | **0.23** | 0.15 |
| Spring | ANN$^{0}$ | **0.85** | 0.81 | 0.05 | 0.00 | 0.02 | 0.12 |
| | FDA$^{4}$ | 0.02 | 0.14 | 0.29 | 0.02 | 0.06 | **0.76** |
| | GAM$^{7}$ | 0.05 | 0.34 | **0.46** | 0.04 | 0.06 | 0.22 |
| | GBM$^{6}$ | 0.06 | 0.14 | **0.33** | 0.17 | 0.19 | 0.26 |
| | GLM$^{4}$ | 0.00 | 0.12 | **0.82** | 0.17 | 0.06 | 0.00 |
| | MARS$^{4}$ | 0.11 | 0.40 | 0.20 | 0.02 | 0.05 | **0.43** |
| | RF$^{3}$ | 0.09 | 0.15 | **0.25** | 0.14 | 0.19 | 0.19 |
| | Mean of means | 0.17 | **0.30** | **0.34** | 0.08 | 0.09 | 0.28 |
| | Ensemble | 0.04 | 0.26 | **0.41** | 0.07 | 0.09 | **0.28** |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Tantabiddi BR
Tantabiddi SZ
Exmouth BR
Mangrove Bay SZ
Indo-Pacific bottlenose dolphin sightings
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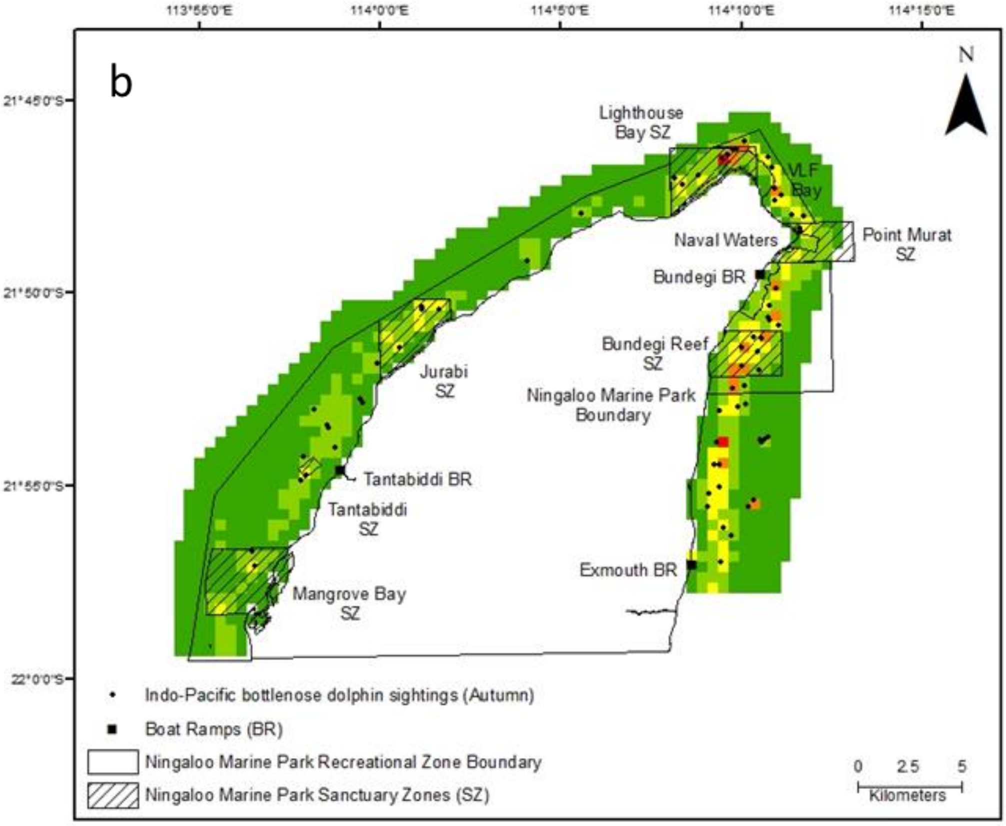
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Point Murat SZ
Bundegi BR
Bundegi Reef SZ
Ningaloo Marine Park Boundary
Jurabi SZ
Tantabiddi BR
Tantabiddi SZ
Exmouth BR
Mangrove Bay SZ
Indo-Pacific bottlenose dolphin sightings (Autumn)
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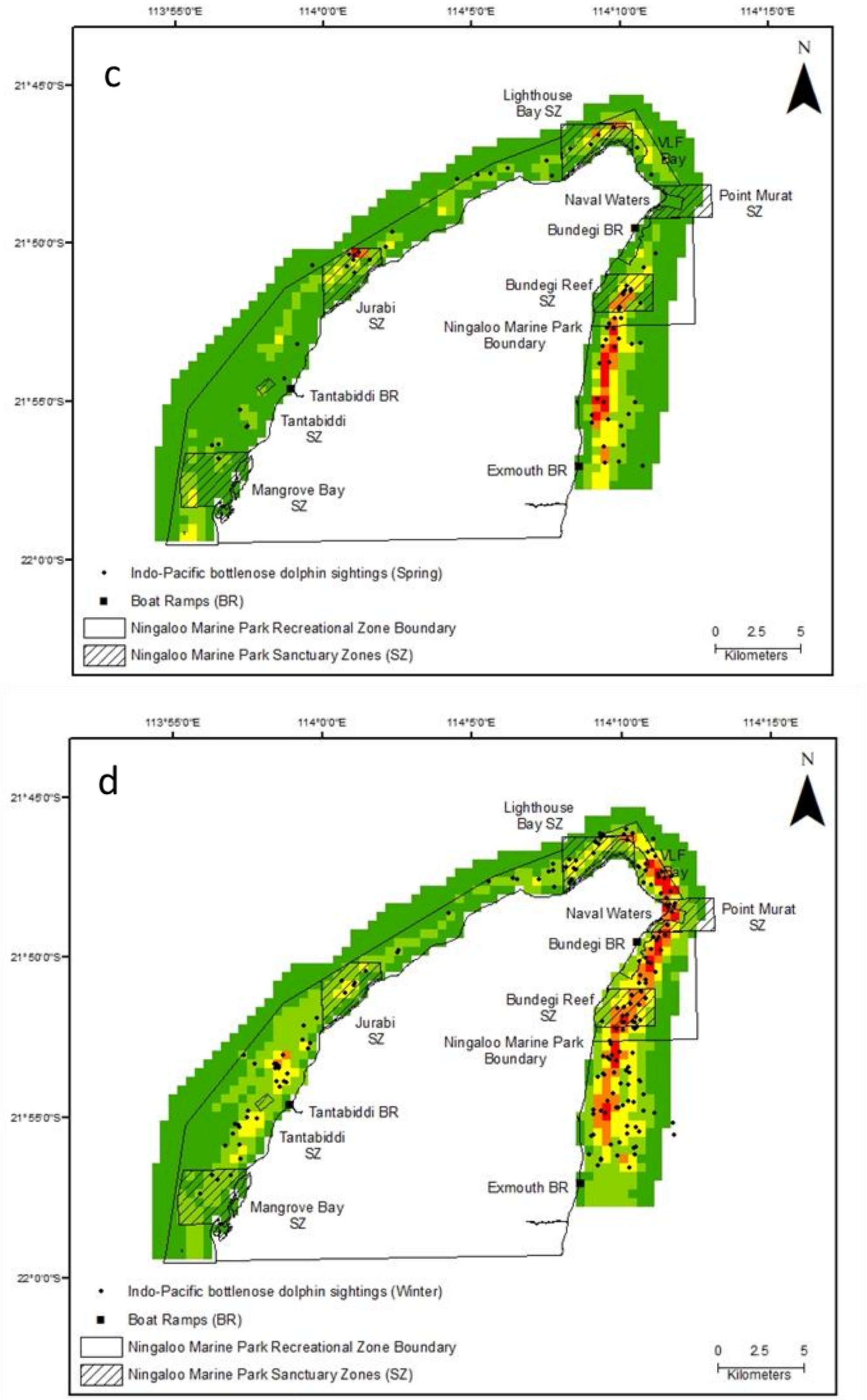


**Figure 3.4:** Ensemble models of Indo-Pacific bottlenose dolphin probability of occurrence at the North West Cape for the overall (a) ensemble and each season (b: autumn; c: winter; and d: spring). Colours as shown in the legend indicate the probability of occurrence 0.00 – 0.40 = low, 0.41 – 0.80 = moderate and 0.81 – 1.00 = high. The General Use zone is the area outside the recreational zone boundary.

**Table 3.4:** Number and proportion (%) of cells with high (>0.81), moderate (0.41-0.80) and low (<0.40) probability of Indo-Pacific bottlenose dolphin occurrence inside and outside the Ningaloo Marine Park (NMP), as well as those cells inside the marine park that fell within designated sanctuary zones (SZ).

| Time Period | Total number of cells | Cells inside the NMP | | Cells in SZ within the NMP | | Cells outside the NMP | |
|---|---|---|---|---|---|---|---|
| | | Number | Proportion | Number | Proportion | Number | Proportion |
| **High Probability of Dolphin Occurrence (>0.81)** | | | | | | | |
| Overall | 39 | 20 | 51% | 4 | 10% | 19 | 49% |
| Autumn | 2 | 1 | 50% | 1 | 50% | 1 | 50% |
| Winter | 20 | 15 | 75% | 1 | 5% | 5 | 25% |
| Spring | 11 | 1 | 9% | 1 | 9% | 10 | 91% |
| **Moderate Probability of Dolphin Occurrence (0.41 to 0.80)** | | | | | | | |
| Overall | 174 | 121 | 70% | 47 | 27% | 53 | 30% |
| Autumn | 74 | 50 | 68% | 31 | 42% | 24 | 32% |
| Winter | 148 | 96 | 65% | 34 | 23% | 52 | 35% |
| Spring | 71 | 36 | 51% | 21 | 30% | 35 | 49% |
| **Low Probability of Dolphin Occurrence (0.00 to 0.40)** | | | | | | | |
| Overall | 721 | 609 | 84% | 95 | 13% | 112 | 16% |
| Autumn | 858 | 699 | 81% | 114 | 13% | 159 | 19% |
| Winter | 766 | 639 | 83% | 111 | 14% | 127 | 17% |
| Spring | 852 | 713 | 84% | 124 | 15% | 139 | 16% |
| **Total study area** | | | | | | | |
| Total | 934 | 750 | 80% | 146 | 16% | 184 | 20% |

## 3.5 Discussion

Bridging information gaps about the spatial and temporal distribution of highly mobile species is critical for their effective management and conservation. Near Threatened Indo-Pacific (IP) bottlenose dolphins are one of the most abundant dolphin species inhabiting the North West Cape (NWC) in Western Australia (WA), an area subject to mixed levels of protection. Despite their high abundance in this region, information on the spatial distribution and habitat preferences of IP bottlenose dolphins at the NWC was lacking, thus preventing spatial conservation prioritisation efforts that consider this species. Prior to this study, habitat preferences for IP bottlenose dolphins had been derived from a broad scale aerial dugong survey, where IP bottlenose dolphins were opportunistically sighted, that largely surveyed waters outside of this study area, with transects moving east across the Gulf (Hanf et al., in review). Results showed the importance of deeper Gulf waters to the IP bottlenose dolphin. In this study, I used ensemble species distribution modelling to predict areas of high probability of IP bottlenose dolphin occurrence in relation to environmental and anthropogenic variables in coastal waters of the NWC. Ensemble models performed better than individual SDM algorithms, thus supporting the effectiveness of this approach for robustly modelling coastal dolphin distribution (Zanardo et al., 2017, Hunt, 2018, Passadore et al., 2018a).

The results of ensemble models revealed that IP bottlenose dolphin distribution in the coastal waters of the NWC was primarily influenced by distance to coast (occurring up to 2000 m from the coast). Areas of high probability of dolphin occurrence were also influenced by other environmental (i.e. water depth and SST) and anthropogenic variables (i.e. distance to the nearest boat ramp and marine park zone) depending on the year and season, indicating spatially and temporally complex range dynamics of the IP bottlenose dolphins using the area. Areas of moderate to high probability of occurrence were found to overlap with multiple designated Sanctuary Zones (subject to the highest level of protection by Government), but also occurred in waters outside the boundaries of the Ningaloo Marine Park (NMP) (i.e. with no statutory protection). The seasonal results suggest that there are some slight shifts in the distribution and probability of occurrence of IP bottlenose dolphins at the NWC across seasons, with higher probability of occurrence (>0.81) during winter and spring. Despite these seasonal changes, waters to the north and east of the NWC consistently featured as areas of high probability of dolphin occurrence. This study revealed the importance of coastal waters of the NWC to IP bottlenose dolphins, highlighting the vulnerability of the species to threats associated with human activities occurring in these areas.

The species distribution models presented here have some limitations as they only involved autumn, spring and winter seasonal data, lacked individual characteristics (e.g. sex and age) and behavioural data that may influence IP bottlenose dolphin distribution. Also, due to small sample sizes, data pooling of seasonal data across years was required, and thus any interannual seasonal variability in species distribution is not represented. Based on the similarities of yearly model outputs (see S2.2 in Appendix 2 of this thesis), I expect that these differences would be negligible. Future SDMs would benefit from inclusion of survey data covering all seasons and areas adjacent to the NWC, biotic variables such as prey and predator availability, and individual parameters (i.e. age, sex, reproductive status and behaviour).

### *3.5.1 Drivers of coastal dolphin distribution in coastal waters at the North West Cape*

#### *3.5.1.1 Prey availability and predation risk*

Both prey availability and predation risk are known to influence dolphin distribution and habitat use (Wirsing et al., 2008, Heithaus and Dill, 2002, Heithaus and Dill, 2006). Studies have found IP bottlenose dolphins feed on a large variety of prey, mainly comprising teleost fishes and cephalopods (Amir et al., 2005, Kiszka et al., 2014, Yamazaki et al., 2008, Kaiser, 2012, Cockcroft and Ross, 1990). The coastal waters of the NWC contain a rich biodiversity of teleost fish species with 550 species recorded along the Ningaloo Coast and more than 780 species in the Exmouth Gulf (Fitzpatrick et al., 2019, Hutchins et al., 1996, McLean et al., 2016). Many fish species (i.e. mackerel, mullet, trevally, emperor, snapper) and cephalopods recorded at the NWC (Fitzpatrick et al., 2019) have been found to be important in the diets of IP bottlenose dolphins elsewhere (Amir et al., 2005, Kiszka et al., 2014). Many additional fish species present in the NWC coastal waters are also likely prey sources for these dolphins (e.g. bream, flounder, flathead, whiting and herring Fitzpatrick et al., 2019). The diet of IP bottlenose dolphins at the NWC is not currently known but individuals have been observed preying on trevally and mullet species (Zachary Bald and Timothy Hunt, personal communication; Haughey, personal observations). At the NWC, the continental shelf falls within close proximity to the coast, subjecting the area to strong localised currents, with enhanced productivity expected at the mouth of the Exmouth Gulf (e.g. Point Murat) as a result of deeper stratified waters mixing with vertically mixed waters from within the Gulf (Verspecht, 2002). It is plausible that the oceanography in this section of the Cape, likely influences aggregations or distribution of important dietary species of IP bottlenose dolphins. Therefore, it is likely that aggregations of these prey species influence dolphin distribution patterns at the NWC. Dolphin prey availability along the west coast of Australia is influenced by the Leeuwin Current, which experiences fluctuations in SST as a result of El Niño Southern Oscillation and La Niña climatic events, driving changes in the distribution of prey (Hanf et al., in review, Sprogis et al., 2017). Although large scale changes in IP bottlenose dolphin distribution have been recorded in the region during the El Niño event of 2015 (Hanf et al., in review), these changes were not observed at the fine scale level in this study.

Killer whales (*Orcinus orca*) and tiger sharks (*Galeocerdo cuvier*) are the most likely predators of IP bottlenose dolphins at the NWC (Pitman et al., 2015, Andrzejacek et al., 2019, Ferreira et al., 2017). Ecotourism charters have reported successful predation attempts on IP bottlenose dolphins by killer whales within the NMP and several photo-identified individuals bear fresh wounds and scars as a result of shark bites (Haughey et al., 2020). Killer whale families are often observed in waters beyond the fringing Ningaloo Reef on the western side of the NWC during June to November (Pitman et al., 2015), potentially influencing the high probability of IP bottlenose dolphin occurrence in close proximity to the coast at the NWC. Additionally, tiger shark biologging data has indicated a preference for inshore habitats at an average water depth of 11.6 m (Andrzejacek et al., 2019), likely overlapping with IP bottlenose dolphin distribution. As such, distribution is often a tradeoff between predation pressure and prey availability. Therefore, future studies looking further into diet, associated prey availability and predation pressure are needed to assess the degree of influence these have on dolphin distribution at the NWC, as has been explored in other areas of WA (Heithaus and Dill, 2002, Heithaus, 2001b, Sprogis et al., 2018c, Smith et al., 2018, McCluskey et al., 2016).

#### *3.5.1.2 Boat traffic*

The NWC, is subject to high commercial and recreational boat pressure resulting from marine tourism and fishing activities (Smallwood et al., 2012, Smallwood and Beckley, 2012). From March to October, whale shark and humpback whale swim tours depart daily from Tantabiddi boat ramp (Sprogis et al., 2020, Catlin and Jones, 2010). Boat presence has been linked to behavioural changes in dolphins including, increased dive times, active avoidance and displacement from preferred habitats (Lusseau, 2003, Steckenreuter et al., 2012b, Bejder et al., 2006, Nowacek et al., 2001). Additionally, risk of boat strike increases as boat numbers and traffic overlaps with the core areas of use by dolphins (Schoeman et al., 2020, Parks et al., 2012, Wells and Scott, 1997). Distance to boat ramp was an influential variable of IP bottlenose distribution in this study, with dolphins more likely to occur in waters within 7000 m from a boat ramp. One of the key boat launch sites at the NWC and where ecotourism often takes place, the Tantabiddi area and surrounding lagoons, experienced low to moderate probability of IP bottlenose dolphin occurrence year-to-year and seasonally. In contrast, many areas of high probability of occurrence on the eastern side of the NWC were situated near Bundegi boat ramp, another key boat launch site. Boat density is highest within coastal lagoons to the west of the NWC, and within waters to the tip and down the east side of the NWC (Smallwood and Beckley, 2012). Thus, the lower probability of occurrence of IP dolphins in the Tantabiddi area may in fact be more indicative of a lack of prey availability in these lagoons, rather than boat presence and should be a topic of future research. Furthermore, given the high degree of overlap between areas of high probability of IP bottlenose dolphin occurrence (this study) and high boat density in waters at the tip and east of the NWC (Smallwood et al., 2012), IP bottlenose dolphin distribution may not be adversely impacted by current levels of vessel traffic.

#### *3.5.1.3 Space and resource competition*

Haughey et al. (2020) suggested that the inter-specific competition with Australian humpback dolphins (*Sousa sahulensis*) or intra-specific competition with other IP bottlenose dolphins might be contributing to the low site fidelity of IP bottlenose dolphins at the NWC. Competition for space and resources may also influence habitat use as has been recorded in other studies (Parra, 2006, Ansmann et al., 2015b, Kiszka et al., 2012). In the broad scale SDM study by Hanf et al. (in review), a clear distinction in humpback dolphin and bottlenose dolphin distribution was observed, with north-eastern coastal waters of the NWC identified as an area of overlap for high habitat suitability for both species. This study did not model the influence of humpback dolphin occurrence on IP bottlenose dolphin distribution or examine ranging patterns of individual bottlenose dolphins. However, distribution modelling using locational data of Australian humpback dolphin groups within the northern NMP, revealed areas of high probability of occurrence from the boundary of the NMP and around the tip of the NWC to Jurabi Sanctuary Zone (Hunt, 2018). Given the degree of overlap in distribution of the two species, it can be inferred that space and resource competition is likely not influencing the distribution of IP bottlenose dolphins. However, the interaction between these two species at the NWC is a subject of current, ongoing research outside the scope of this study.

### *3.5.2 Implications for conservation and management*

Incorporating spatial and temporal movement patterns of populations into marine park planning, identifies particular sites of high management value, and thus, highlights which sites should be delineated for management in Marine Protected Areas (MPAs) (Schofield et al., 2013, Hooker et al., 1999, Hoyt, 2011). Without the inclusion of adequate spatial and biological information, habitats can be over- or under-protected and managers should account for species that exhibit seasonal variations to their distribution, movement patterns and habitat use when designating MPA boundaries and establishing zoning arrangements (Dwyer et al., 2020, Hartel et al., 2015, Hooker et al., 2011, Guisan et al., 2013).

This study has highlighted the importance of the north-western coastal waters of the Exmouth Gulf to Near Threatened IP bottlenose dolphins and as such, their relevance for conservation and management of this species. Species with nearshore distributions are potentially vulnerable to increasing and cumulative anthropogenic stressors connected with increased use of coastal areas, particularly those experiencing low levels of protection (Karczmarski et al., 2017, Davidson et al., 2012, Cardillo et al., 2005, Cagnazzi et al., 2020). In this study, areas of moderate to high probability of occurrence overlapped moderately with designated Sanctuary Zones within the NMP, but also occurred in waters outside the boundaries of the NMP. Designated Sanctuary Zones prohibit extractive activities (i.e. fishing), and provide potential aggregations of prey. However, in multiple use zones and outside the NMP, IP bottlenose dolphins are exposed to a variety of anthropogenic threats such as recreational and commercial fishing (although commercial fishing is not permitted in Recreational Zones) and boat traffic.

I have no evidence to reject the idea that the NMP is already providing conservation benefits to the IP bottlenose dolphin, considering the NMP is likely contributing to the conservation of other species that interact with individuals of the population (i.e. prey species in no-take zones), and does already encompass a large proportion of key dolphin habitat. However, the NMP establishment and zoning did not consider the distribution and abundance of marine top predators such as IP bottlenose dolphins. Thus I recommend that data presented here should be taken into account in future zoning reviews and adaptive management efforts of the NMP given the high abundance, reliance on coastal waters, and ecological importance of IP bottlenose dolphins in the NWC region, particularly as top predators (Haughey et al., 2020). Such adaptive management efforts have proven beneficial for the protection of apex and meso-predators in the Great Barrier Reef Marine Park (GBRMP; Fraser et al., 2019), where preceding management and results of research and monitoring were combined, to increase the protection of biodiversity in the GBRMP (Kenchington and Day, 2011).

In addition, my results show that IP bottlenose dolphins use waters outside the NMP, where dolphins are at risk of extractive activities that occur in the Exmouth Gulf. Yet, the extent of IP bottlenose dolphin distribution in Exmouth Gulf, associated population structure and impacts of anthropogenic activities on IP bottlenose dolphins still remain unknown. As such, future research directed at assessing the spatial distribution, abundance, habitat use and population genetic structure of IP bottlenose dolphins in Exmouth Gulf would allow management to determine the importance of Gulf waters to this species. Such studies in conjunction with Environmental Impact Assessments (EIAs) should facilitate the development of management efforts to reduce threats to this species, whilst being able to continue economically important anthropogenic activities (i.e. tourism related activities) (Schofield et al., 2013).

Results of this study will assist managers with future adaptive marine park zoning, subsequent management plans of this area and highlight important areas within the range of this Near Threatened species at the NWC. Further, this study provides key information on IP bottlenose dolphin distribution and habitat use in the northern NMP and adjacent coastal waters. In future, the key information presented here, can be built upon with additional research and monitoring at the NWC to assess any reductions in range which may be indicative of a more vulnerable conservation status (IUCN Standards and Petitions Committee., 2019).

# 4 CHAPTER 4: BEHAVIOURAL PROCESSES UNDERLYING HABITAT SELECTION OF INDO-PACIFIC BOTTLENOSE DOLPHINS (*TURSIOPS ADUNCUS*) IN THE NINGALOO MARINE PARK AND EXMOUTH GULF, WESTERN AUSTRALIA.

## 4.1 Abstract

Identifying the behavioural processes (e.g. foraging, resting and travelling) influencing habitat use is important for understanding the behavioural and spatial ecology of species, and informing their conservation. In this study, I collected information on the behavioural state of Near Threatened Indo-Pacific (IP) bottlenose dolphins (*Tursiops aduncus*) inhabiting coastal waters at the North West Cape (NWC), Western Australia (WA). Behavioural data were collected during boat-based surveys from 2013 to 2015 and from 2018 to 2019. I then used ensemble species distribution modelling to identify key environmental and anthropogenic variables influencing the spatial distribution of dolphin schools engaged in foraging, travelling, and resting behaviours. Resting behaviours were more localised and most likely to occur in shallow waters (5 – 10 m deep) within designated Sanctuary Zones within the Marine Park. The distribution of foraging schools was influenced by distance from the nearest boat ramp and seabed slope, with the behaviour more likely to occur 3000 – 5000m from the nearest boat ramp and in areas of moderate seabed slope. Travelling behaviour was influenced by distance to coast and water depth, and was more likely to occur 1000 – 2000 m from the coast and in water depths of 7-12 m, but as deep as 20 m. Areas of high probability of occurrence for each behaviour fell within the Ningaloo Marine Park (NMP) as well as outside the current marine park boundaries. I identified candidate areas for ‘go-slow’ zones, additional Sanctuary Zones and marine park expansion that would benefit the management and conservation of this Near Threatened species. The integration of behavioural data into species distribution models allowed for the identification of areas of importance for key biological activities and insights into how behavioural processes and environmental and anthropogenic conditions influence IP bottlenose dolphin

distribution at the NWC. Given the increasing risks to marine mammals from cumulative anthropogenic activities, such analytical approaches are needed for effective conservation and management of critical areas.

## 4.2 Introduction

Most animals inhabit environments where resources are patchily distributed, influencing movement and spatial utilisation (O'Neill et al., 1988, Russell et al., 1992). Understanding the underlying function behind the spatial distribution of threatened species is essential for their management and conservation (Morrison et al., 2012, Beerens et al., 2015). Resource selection and ultimately habitat selection are hierarchical processes in which animals actively select and exploit habitats at different spatial and temporal scales. In particular, such processes are based on their physiological constraints, life history strategies, costs associated with accessing adequate areas, behavioural needs or a combination thereof (Manly, 2002, Johnson, 1980, McLoughlin et al., 2010). As a result, within the geographic range of a species, animals often differ in the selection of their individual ranges, their preferences for general features (e.g. habitat) within these ranges and the way they use particular elements within these habitats (i.e. selection of foraging sites or appropriate resting areas) (Manly, 2002).

Assessing the function of habitats to wildlife involves determining the purpose for which particular patches of habitat have been selected for, and how this preference may have been influenced by fitness benefits and/or responses to the heterogeneous distribution of resources (Lele et al., 2013, Beerens et al., 2015, Losier et al., 2015, Mabille et al., 2012). For example, often habitat selection may occur as a trade-off, in which animals select risky habitats with higher food availability or safer habitats with lower quality food sources (Maurtizen et al., 2003). Therefore, understanding the behavioural processes and environmental variables driving wildlife-habitat associations is useful for understanding species ecological needs, identifying critical habitats, and guiding conservation actions (Losier et al., 2015, Fortin et al., 2008). Critical habitats can be defined as areas where behaviours that are important for population success, such as foraging, breeding, nursing, socialising and resting, take place (Lusseau and Higham, 2004, Hoyt, 2011). To mitigate the negative impacts of human disturbance on animal populations, analysis of behavioural data in combination with spatial data can identify the functional use of habitats, and therefore, areas of importance for critical behaviours where individuals are most sensitive to anthropogenic pressure, habitat degradation and loss (Ashe et al., 2010, Zanardo et al., 2017, Palacios et al., 2013).

In aquatic environments, several species of cetaceans have shown preferences for certain sites within their range that are used more frequently for specific behaviours (Keith et al., 2013, Hastie et al., 2004, Tyne et al., 2015, Moreno and Matthews, 2018, Zanardo et al., 2017, Heithaus and Dill, 2006, Weir et al., 2008, Dwyer et al., 2020, Filby et al., 2017). With an ever-increasing human presence in coastal environments largely overlapping with the distribution of marine mammals and increasing their extinction risk, understanding how marine mammals use space and identifying key habitats for conservation prioritisation is becoming increasingly important for effective management decisions (Avila et al., 2018, Davidson et al., 2012, Passadore et al., 2018a). Habitat use studies typically examine species-environment relationships to determine environmental, biological and anthropogenic conditions driving distribution patterns (Abrahms et al., 2019, Heithaus and Dill, 2002, Heithaus and Dill, 2006, Passadore et al., 2018a, Dwyer et al., 2020, Sprogis et al., 2018a). However, the underlying behavioural processes by which cetaceans choose particular habitats is unclear, as presence does not indicate function (Hastie et al., 2004, Zanardo et al., 2017, Palacios et al., 2013).

A moderately large (311-370 individuals) number of Near Threatened Indo-Pacific (IP) bottlenose dolphins (*Tursiops aduncus*) inhabit coastal waters at the North West Cape (NWC), Western Australia (WA) (see Chapters 2 and 3 of this thesis and Haughey et al., 2020). These waters are situated within the World Heritage listed Ningaloo Marine Park (NMP) and include adjacent waters outside these boundaries. At the NWC, IP bottlenose dolphins have shown a clear preference for waters close to the coast (up to 2000 m) located to the north and east of the NWC, both inside and outside of the NMP (see Chapter 3). The preference for this section of the NWC, and waters close to the coast is most likely due to a combination of factors including: response to prey availability (with the NWC home to a rich biodiversity of teleost fish species); avoidance of coastal lagoons on the west side of the NWC due to presence of predatory tiger sharks (*Galeocerdo cuvier*) and; avoidance of offshore waters beyond the reef crest on the western side of the NWC due to the presence of predatory killer whales (*Orcinus orca*) (see Chapter 3). However, the function behind the spatial distribution of IP bottlenose dolphins inhabiting coastal waters at the NWC, is not yet known.

To aid in the management and conservation of IP bottlenose dolphins at the NWC and improve our understanding of the spatial ecology of this Near Threatened coastal delphinid, I used behavioural data and ensemble species distribution modelling to; (1) investigate the spatial distribution patterns of schools of dolphins engaged in foraging, resting and travelling behaviours, and their relation to key environmental and anthropogenic variables thought to influence dolphin distribution, and (2) identify areas of importance for foraging, resting and travelling across the NWC.

## 4.3 Methods

### *4.3.1 Study site*

The study site comprised the inshore coastal waters of the North West Cape (NWC) in north-western Australia, and spans from the Exmouth boat ramp in the Exmouth Gulf, around the tip of the cape to Mangrove Bay on the western side of the NWC (Figure 4.1). Approximately 150 $km^2$ of the 237 $km^2$ study area falls within the Ningaloo Marine Park (NMP), while the remaining 87 $km^2$ falls within the Exmouth Gulf. Boat-based surveys for Indo-Pacific (IP) bottlenose dolphins in this study took place both inside and outside the boundary of the NMP (Figure 4.1).

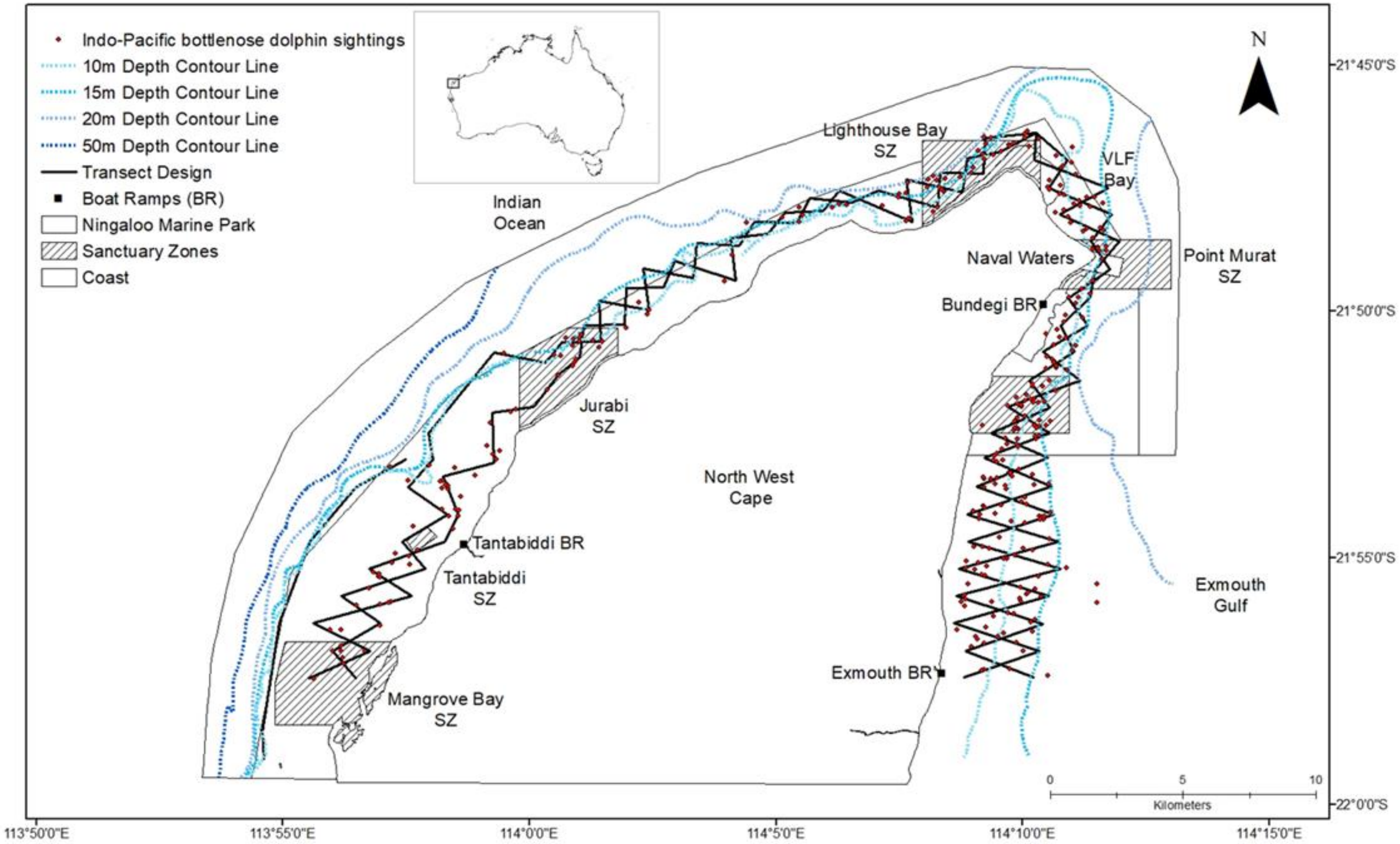


**Figure 4.1:** Map of the North West Cape study area showing the opposing zig zag transect lines, Indo-Pacific dolphin (*Tursiops aduncus*) sightings, depth contour lines (10, 15, 20 and 50 m), boat ramps and the Ningaloo Marine Park zoning, including designated Sanctuary Zones. Inset, is a map of Australia, showing the location of the North West Cape.

The western side of the cape is characterised by shallow lagoons (<5 m deep) with sandy substrates, coral communities and a subtidal fringing coral reef system (CALM and MPRA, 2005, Cassata and Collins, 2008). Beyond the subtidal ocean edge of the reef, the continental shelf drops off quickly, exposing the reef to considerable wave action (e.g. swell height >2 m) (Cassata and Collins, 2008, CALM and MPRA, 2005, Collins et al., 2003). On the eastern side of the NWC is a large sub-tropical inverse estuary (Exmouth Gulf) which reaches depths of 21 m (mean depth of 10-12 m) (Fitzpatrick et al., 2019, Ayukai and Miller, 1998, Brunskill et al., 2001). The Gulf is characterised by mostly subtidal sandy bottoms and limestone reefs (Lyne et al., 2006, Fitzpatrick et al., 2019, Brunskill et al., 2001, Twiggs and Collins, 2010). The Exmouth Gulf has not received as much attention as the NMP and as such, many knowledge gaps exist within this environment, posing problems for its overall conservation and management (Fitzpatrick et al., 2019).

The NMP is managed using a zoning system with Sanctuary, Recreational, Special Purpose (Shore-Based) and General Use Zones. Sanctuary Zones, also termed ‘no take zones’ are areas where extractive activities such as fishing are prohibited (CALM and MPRA, 2005). Recreational Zones allow recreational fishing (CALM and MPRA, 2005). In General Use Zones, sustainable commercial activities are permitted in addition to recreational fishing (DoEH, 2002, CALM and MPRA, 2005). In the Special Purpose (Shore-Based) Zones, recreational line fishing from the beach is permitted. These zones are located along the beaches adjacent to the Point Murat, Lighthouse Bay and Jurabi Sanctuary Zones (Figure 4.1) (CALM and MPRA, 2005). In the area zoned as Naval Waters, no fishing is permitted within 400 m of the pier and boats are not permitted to stop or anchor in these waters (DoT., 2019). Outside the NMP boundaries, there is no restriction on activities permitted.

### *4.3.2 Data collection*

Boat based surveys searching for IP bottlenose dolphins were conducted onboard a 5.6 m aluminium vessel during the hours of 0700 and 1800 from May to October in 2013, April to October in 2014, May to October in 2015 and April to September in both 2018 and 2019. Surveys were conducted in favourable weather conditions (i.e. Beaufort Sea State of ≤3 and no rain), spanning the austral seasons of Autumn (March - May), Winter (June - August) and Spring (September – November). Due to consistently unfavourable wind conditions, extreme temperatures and higher risk of tropical cyclones, surveys were not conducted over the austral summer and early autumn period (December – February, and March respectively). A crew of three to five (mode = four) observers searched for dolphins forward of the vessel’s beam using a combination of the naked eye and 7 x 50 zoom binoculars. While searching for dolphins a systematic line transect layout was followed (2 x 93 km opposing zig zag lines and 1 x 13 km single line) covering a wide range of habitats, human use areas and environmental gradients within the study area.

When a single dolphin or a school of dolphins was sighted (see Chapter 2 of this thesis for how this was defined), search effort was suspended, and dolphins were approached to within 30 m to record a GPS location. At this location, the initial predominant behaviour (i.e. behavioural state in which more than 50% of the animals in the group were involved) (see Table 4.1; modified from Shane (1990), Mann (1999) and Lusseau (2003)) and environmental data (i.e. water depth, sea surface temperature and water visibility) were collected. In addition, environmental data were collected *in situ* at the beginning and end point of transects, and at various random locations throughout the survey area. Water depth was recorded using the research vessel’s depth sounder, sea surface temperature (SST) was recorded using a handheld multi-parameter probe, and water visibility was measured using a secchi disk

**Table 4.1:** Definitions of the behavioural states of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) (modified from (Shane, 1990, Lusseau, 2003, Mann, 1999) used during boat based surveys of the coastal waters of the North West Cape, Western Australia.

| **Behaviour** | **Definition** |
|---|---|
| Foraging | Individuals move in various directions without an obvious pattern. Dolphins dive frequently and steeply downwards with extended submersion times. Rapid accelerations and erratic movements at the surface, indicative of animals chasing fish. Animals seen directly pursuing a fish or with fish in their mouth. |
| Milling | Dolphin movements are slow and with no apparent direction. Individuals surface facing different directions, resulting in no net movement. Dolphins swim in close proximity but with no interaction. Group spacing varies. No aerial behaviour, activity levels are low. Dolphins surface in a synchronised manner and most of the time is spent at the surface of the water. Dive intervals vary but are generally short. |
| Resting | Dolphins engaged in very slow movements as a tight group at the surface. Often seen stationary. |
| Socialising | Localised movement. Dive direction and intervals vary. Dolphins in close proximity showing high levels of interaction (i.e. animals making physical contact with each other and rubbing bodies). Lots of splashing. Fins and flukes often break the surface of the water. ‘Head out’ behaviour often observed. Often aerial behaviour such as leaps and body slaps are observed. |
| Travelling | Individuals move steadily in a constant direction. Swimming with short, relatively constant dive intervals. Group spacing varies. Shallow dive angles. Animals are not underwater for extended lengths of time. |
| Unknown | Behaviour cannot be classified as one of the above mentioned or animals not seen for more than 5-7 minutes (not at surface nor underwater). |

### *4.3.3 Data analysis*

#### *4.3.3.1 Frequency of behaviours*

Chi-squared tests of independence were run in R Studio (RStudio Team., 2019) to determine if there was any statistical difference in the frequency of behaviours across austral seasons.

#### *4.3.3.2 Response and predictor variables*

ArcMap version 10.7 (ESRI) was used to create spatial layers of response (presence-absence of dolphins engaged in particular behavioural state) and predictor variables (see Table 4.2) at a 500 x 500 m grid resolution. This resolution ensured sufficient detail of each variable throughout the study area. All spatial layers were projected to Universal Transverse Mercator zone 50 South, based on the WGS 1984 datum. The GPS locations of dolphin schools engaged in each behavioural state sighted whilst on transect, and survey tracks were imported into ArcMap to create a presence-absence grid considering survey effort. To ensure independence of data points due to bottlenose dolphins exhibiting flexible grouping patterns (Wells et al., 1987) and to avoid effects from the presence of the research vessel on school behaviour, only the locational point where the initial group members were first encountered whilst on transect and the predominant behaviour observed at the onset were included in analysis. Due to the small number of schools encountered within each austral season for which behavior was determined, I pooled data over all five years to build species distribution models for each relevant behavioral state.

Each 500 x 500 m cell within the survey area was assigned either a 1 (i.e. presence of an individual or school engaged in the relevant behavioural state for each model) or 0 (i.e. absence of individuals engaged in the behavioural state). In order to reduce false absences (i.e. determining an absent cell when individuals may in fact engage in that behaviour in that area), absence cells were defined based on areas which had the highest survey effort (Phillips et al., 2009). Survey effort was quantified using the total area of 'on-effort' survey tracks within each 500 x 500 m grid cell. A buffer of 250 m was added either side of each transect line, which was considered to be the average distance from the vessel that dolphins could reliably be observed under a variety of sea conditions (Zanardo et al., 2017, Hunt, 2018). Grid cells were ranked according to the amount of survey effort within and cells containing no dolphin presence and survey effort higher than the mean were considered most likely to represent true absences. These grid cells were defined as absence cells for the purpose of this study (Zanardo et al., 2017, Hunt, 2018, Passadore et al., 2018a).

Predictor variables that were used to model the distribution of IP bottlenose dolphins across different behavioural states were classified as; abiotic (i.e. water depth, slope, sea surface temperature (SST), distance to coast and water visibility), anthropogenic (i.e. distance to boat ramp and marine park zone) and biotic (i.e benthic habitat type; for the NMP portion of the study area only) (Table 4.2). Predictor variables used in this study were selected because they are known or have been suggested to affect the presence of bottlenose dolphins or their prey, with some variables acting as proxies for prey distribution (i.e. SST), predation risk (i.e. water visibility), and areas of high human use and anthropogenic disturbance (i.e. distance to boat ramp and marine park zone). (Ingram and Rogan, 2002, Sprogis et al., 2018a, Passadore et al., 2018a, Zanardo et al., 2017, Heithaus and Dill, 2002).

It was chosen to include covariate data collected in situ while surveying for IP bottlenose dolphins in the modelling process for a number of reasons. Firstly, available remote sensing data did not cover the entire study area, excluding waters close to the coast. Secondly, the resolution of available remote sensing data is not suitable for the fine-scale resolution, 500m x 500m grid cell size, used in this study. Thirdly, as the covariate data was collected during the time of dolphin surveys it is considered the most accurate environmental data for that period. Benthic habitats have not been mapped for the Exmouth Gulf and as such benthic habitat data only exists for the NMP portion of the study area. To assess if benthic habitat type is an important variable influencing IP bottlenose dolphin distribution according to behaviour, Species Distribution Models (SDMs) were first built for the NMP separately. Habitat type was classified as either mobile sand, mangroves, bare reef (intertidal), coral reef (intertidal), bare reef (subtidal), macro algae (subtidal), coral reef (subtidal), saltmarsh and pelagic (see S3.1, Table S3.1 for habitat type definitions, in Appendix 3 of this thesis). The NMP SDMs were run using the same methods detailed in section *4.3.3.4 Model algorithms: selection, building, estimates and performance*. Habitat type was not found to be among the influential variables driving the location of dolphins engaged in particular behaviours (see S3.2 for NMP model results and AUC values and S3.6 for model response curves, in Appendix 3 of this thesis); thus, I present here SDMs for the entire study area without habitat type as a predictor variable.

**Table 4.2:** List of predictor variables used in species distribution modelling (SDM) of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the coastal waters of the North West Cape (NWC), their associated data source and how they were derived in ArcMap. * indicates the variable was only included in Ningaloo Marine Park (NMP) SDMs. Spatial resolution for each variable is 500 x 500m.

| Type of variable | Predictor variable | Variable abbreviation | Data Source |
|---|---|---|---|
| Abiotic | Distance to coast | N/A | Derived using the Euclidean distance tool (Spatial Analyst toolbox). |
| Abiotic | Slope | Slope | Derived using the Slope tool and is measured in decimal degrees (Spatial Analyst toolbox). |
| Abiotic | Sea surface temperature | SST | Derived from *in situ* measurements of SST. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size)(Spatial analyst toolbox). |
| Abiotic | Water depth | Depth | Derived from *in situ* measurements of depth. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst toolbox). |
| Abiotic | Water visibility | N/A | Derived from *in situ* measurements of water visibility using a secchi disk and calculated as a proportion of the total depth.<br>Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst Toolbox). |
| Anthropogenic | Distance to boat ramp | N/A | Exmouth, Bundegi and Tantabiddi boat ramps are established vessel launch sites in the study area.<br>Derived using the Cost distance tool (Spatial Analyst toolbox) and the coast shapefile as the cost surface. |
| Anthropogenic | Marine park zone | NMP Zone | NMP zoning shape file which shows the zone boundaries was obtained from the Western Australian Government Department of Biodiversity, Conservation and Attractions service. Variable according to MP zone was assigned to each grid cell using the polygon to raster tool (1=General Use, 2=Recreational, 3=Sanctuary, 4= Special Purpose, 5 = Naval Waters, 6 = outside the NMP) (DPaW. and DoF., 2014) |
| Biotic* | Benthic habitat/substrate | Habitat | This data was derived from a broad scale benthic habitat study of the NMP (DPaW., 2006, Lucieer et al., 2017, Bancroft and Sheridan, 2000). Habitat type was classified as either 1=mobile sand, 2=mangroves, 3=bare reef (intertidal), 4=coral reef (intertidal), 5=bare reef (subtidal), 6=macro algae (subtidal), 7=coral reef (subtidal), 8=saltmarsh and 10=pelagic (No habitat type associated with a value of 9 (mudflat) is |

| Type of variable | Predictor variable | Variable abbreviation | Data Source |
|---|---|---|---|
| | | | present in this section of the NMP). For habitat type definitions, see S3.1, Table S3.1 (Appendix 3). Each grid cell was assigned a variable according to habitat type using the polygon to raster tool. |

#### *4.3.3.3 Collinearity of predictor variables*

Before running the SDMs, I tested for collinearity among explanatory variables using stepwise procedures within the usdm package in RStudio (Naimi, 2015). Variance Inflation Factors (VIF) were calculated for all variables. Variable pairs with a maximum linear correlation greater than the threshold (0.7) were identified using ‘vifcor’ and the variable with the highest variance inflation factor (VIF, threshold = 3) was excluded using ‘vifstep’ (Zuur et al., 2010). These procedures were repeated until there was no variable remaining with a correlation coefficient greater than 0.7 and no variables with a VIF greater than the threshold (Naimi et al., 2014).

#### *4.3.3.4 Model algorithms: selection, building, estimates and performance*

Multiple modelling techniques have been developed to model species distribution, but the best performing models vary, with no model consistently superior in performance across studies, species and regions (Araujo and New 2007, Elith and Graham 2009, Marmion et al. 2009). Ensemble modelling has become increasingly popular, combining multiple single model predictions to reduce bias of single model approaches and to produce more robust estimates of species distributions through a ‘consensus’ approach (Araujo and New 2007, Thuiller et al. 2009, Hao et al. 2019). Ensemble modelling has been successfully applied to marine taxa (Riul et al. 2013, Pikesley et al. 2015, Alabia et al. 2016, Abrahms et al. 2019) including coastal dolphins (Hanf 2015, Zanardo et al. 2017, Hunt 2018, Passadore et al. 2018).To model the distribution of IP bottlenose dolphins engaged in different behavioral states in relation to explanatory variables, I used an ensemble modelling approach that combined results from seven different modelling algorithms; artificial neural network (ANN) (Ripley, 1996), flexible discriminant analysis (FDA) (Hastie et al., 1994), generalised additive model (GAM) (Hastie and Tibshirani, 1990), generalised boosted model (GBM) (Friedman et al., 2000), generalised linear model (GLM) (McCullagh and Nelder, 1989), multivariate adaptive regression splines (MARS) (Friedman, 1991) and random forest (RF) (Breiman, 2001) using the BioMod2 package in RStudio (Thuiller et al., 2009). Settings associated with each algorithm are presented in S3.3, in Appendix 3 of this thesis.

SDM's were built using a binomial error distribution with logit as the link function. I implemented a 10-fold cross-validation method for each SDM and a random data splitting procedure of 75/25% for model calibration and testing (Thuiller et al., 2009). Explanatory variable importance was determined using a randomized 10-permutation run procedure within BioMod2 (Thuiller et al., 2009). This allows for a direct comparison between individual model algorithms and calculates the Pearson's correlation between the standard predictions and predictions where one variable has been randomly permutated. High correlation (i.e. little difference between the two predictions) indicates that the variable is not important, whereas a low correlation indicates that the variable is important. Variables are ranked from 0 to 1 according to the mean correlation coefficient, with the highest ranked variable assigned as the most influential and the lowest ranked, the least influential (Thuiller et al., 2009).

SDMs that use presence-absence data have the potential to produce false positives, predicting species occurrence in areas where the species does not occur and false negatives where they fail to predict species occurrence in areas where the species does occur (Guisan and Thuiller, 2005). To evaluate SDM performance, prediction accuracy, compare modelling algorithms, and for comparability with other studies, I used the AUC metric which has been widely used in many SDM studies (Fielding and Bell, 1997). Values of AUC range from 0 to 1; with values >0.5 indicating that the model predictions perform better than random, whereas values <0.5 indicate that the model predictions are no better than what would be expected by chance. In general, AUC values of 0.5 – 0.7 are considered low and represent poor model performance, values of 0.7 – 0.9 are considered moderate to good, and values above 0.9 represent excellent model performance (Peterson et al., 2011). As such, all runs that performed poorly (AUC <0.7) were excluded from the final ensemble model.

All SDM analysis is also explained in S3.4, in Appendix 3 of this thesis, following the Overview, Data, Model, Assessment and Prediction (ODMAP) protocol recommended by Zurell et al. (2020).

## 4.4 Results

### *4.4.1 Survey effort and Indo-Pacific bottlenose dolphin encounters and behaviour*

Over the five years of study, almost 723 hours of survey effort were completed (Table 4.3). Survey effort varied slightly between years and austral seasons due to variability in weather conditions. Overall, the highest survey effort and number of dolphin sightings occurred during the winter months (June-August). In total, 323 Indo-Pacific (IP) bottlenose dolphin schools were encountered: 111 travelling, 79 foraging, 53 resting, 29 socialising, 26 milling and 25 of unknown behaviour.

Travelling, foraging and resting were the most commonly observed behaviours during surveys, contributing to 34%, 24% and 16% of sightings respectively (Table 4.2). As socialising and milling behaviours were observed less frequently (n = 29 and 26, respectively), both had a sample size too small to model (<40 sightings) and thus were excluded from analyses. Dolphin resting behaviour showed a significant level of variation in frequency between seasons ($X^2$ = 16.28, df = 2, p = <0.001) with resting groups most commonly observed in spring than in autumn and winter. The frequency of foraging and travelling did not vary between seasons (foraging; $X^2$ = 1.29, df = 2, p = 0.5247 and travelling; $X^2$ = 4.32, df = 2, p = 0.12).

**Table 4.3:** Summary of boat survey effort (hours) and number of dolphin schools encountered foraging, resting and travelling between 2013 to 2015 and 2018 to 2019 at the North West Cape, Western Australia. The numbers in brackets in the overall row represent the number of 500 x 500 m grid cells with dolphin school presences used to model Indo-Pacific bottlenose dolphin distribution across the entire study area according to behavioural state.

| Time period | Survey effort (hours) | Number of foraging dolphin schools | Probability of foraging per hour of survey effort (%) | Number of resting dolphin schools | Probability of resting per hour of survey effort (%) | Number of travelling dolphin schools | Probability of travelling per hour of survey effort (%) |
|---|---|---|---|---|---|---|---|
| Autumn (April - May) | 217.55 | 21 | 10 | 13 | 6 | 20 | 9 |
| Winter (June – August) | 356.15 | 44 | 12 | 19 | 5 | 72 | 20 |
| Spring (September - October) | 149.10 | 14 | 9 | 21 | 14 | 19 | 13 |
| Overall | 722.78 | 79 (62) | 11 | 53 (44) | 7 | 111 (84) | 15 |

### *4.4.2 Collinearity*

Correlation testing revealed collinearity between water visibility and water depth, when pooling all environmental data together to produce overall functional use of habitat SDMs (r = 0.77). Testing also revealed a VIF of >3 for water depth (VIF = 5.34). Due to the ecological and biological importance of water depth reported in other coastal bottlenose dolphin habitat use studies (Heithaus and Dill, 2002, Heithaus and Dill, 2006, Zanardo et al., 2017, Passadore et al., 2018a, Sprogis et al., 2018a, Vargas-Fonesca et al., 2018), it was decided to remove water visibility as an explanatory variable rather than water depth. Thus, six explanatory variables were included in the SDMs; distance to boat ramp, distance to coast, marine park zone, seabed slope, SST and water depth.

### *4.4.3 Ensemble models of dolphin distribution according to behaviour*

#### *4.4.3.1 Foraging*

Most of the single foraging behaviour SDMs performed well, with moderate to good AUC values (AUC values ranged from 0.42– 0.86; median = 0.76, Figure 2), except for several runs from the ANN and GLM algorithms. The foraging ensemble model outperformed all single SDMs with an AUC of 0.97, indicating excellent model performance (Figure 4.2).

The ensemble models detailing the probability of occurrence of IP bottlenose dolphins engaging in foraging behaviours in the coastal waters of the NWC revealed core areas where this behavioural state was more likely to occur. Important areas for foraging were widespread in the Exmouth Gulf and situated in coastal lagoons to the west of the NWC (Figure 4.3). When modelling all foraging data, this behaviour was found to be mostly linked to distance to boat ramp (0.41) and seabed slope (0.31) (Table 4.4), with the mean of means additionally supporting distance to coast. Response curves indicated that foraging behaviours were more likely to occur at 3000 m - 5000 m from the nearest boat ramp, in areas of moderate seabed slope (0.4°-0.6°) and 1000 – 2000 m from the coast (see S3.5.1, in Appendix 3 of this thesis).

**Table 4.4:** Importance of environmental and anthropogenic variables for the single and ensemble species distribution models of foraging Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) at the North West Cape, Western Australia. Seven model algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA) (Hastie et al. 1994), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as an ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| **Foraging** | | | | | | |
|---|---|---|---|---|---|---|
| **Explanatory variables** | | | | | | |
| **Model** | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** |
| ANN$^{1}$ | **0.88** | 0.76 | 0.11 | 0.05 | 0.03 | 0.10 |
| FDA$^{8}$ | 0.35 | 0.31 | 0.17 | **0.59** | 0.07 | 0.12 |
| GAM$^{10}$ | 0.26 | **0.40** | 0.34 | 0.20 | 0.03 | 0.14 |
| GBM$^{10}$ | **0.42** | 0.16 | 0.11 | 0.27 | 0.21 | 0.13 |
| GLM$^{6}$ | 0.31 | 0.00 | **0.58** | 0.18 | 0.00 | 0.01 |
| MARS$^{10}$ | 0.42 | **0.46** | 0.06 | 0.25 | 0.04 | 0.07 |
| RF$^{10}$ | **0.28** | 0.16 | 0.11 | 0.19 | 0.22 | 0.18 |
| Mean of means | **0.36** | **0.29** | 0.20 | 0.22 | 0.09 | 0.15 |
| Ensemble | **0.41** | 0.28 | 0.26 | **0.31** | 0.07 | 0.09 |

Foraging behaviours were concentrated to the east side of the NWC with core foraging areas (i.e. high probability of occurrence >0.81) located in the Recreational Zones waters adjacent to the Point Murat Sanctuary Zone boundaries and the Naval Waters (74%), and outside the NMP in the Exmouth Gulf (26%) (Figure 4.3, Table 4.7). Almost continuous moderate probability of occurrence (0.61 – 0.80) grid cells for foraging behaviours extended from the eastern boundary of the Lighthouse Bay Sanctuary Zone, outside the NMP to the south-eastern limit of the study area (Figure 4.3).

#### *4.4.3.2 Resting*

Most of the single SDMs for resting behaviour, performed well with moderate to good AUC values (AUC values ranged from 0.54 – 0.82, median = 0.71, Figure 4.2), except the majority of runs from the ANN algorithm. The resting behaviour ensemble model outperformed all single SDMS with an AUC of 0.95 (Figure 4.2).

Ensemble modelling of resting hotspots for IP bottlenose dolphins at the NWC identified distinct localised areas where resting behaviour was more likely to take place (Figure 4.3). Modelling all resting data collected over the five survey years, showed this behavioural state was linked to marine park zone (0.43) and water depth (0.38) (Table 4.5). Response curves indicated that resting behaviours were more likely to occur in marine park zone 3 (Sanctuary Zones) and in water depths of 5 – 10 m (see S3.5.2, in Appendix 3 of this thesis).

All cells with high probability of occurrence (>0.81) of dolphins resting and most (85%) with moderate probability (0.61 – 0.80) were located in generally sheltered coastal waters and within the boundaries of the designated Sanctuary Zones; Mangrove Bay, Tantabiddi, Jurabi, Lighthouse Bay and Bundegi Reef (Figure 4.3, Table 4.7).

**Table 4.5:** Importance of environmental and anthropogenic variables for the single and ensemble species distribution models of resting Indo-Pacific bottlenose dolphins (Tursiops aduncus) at the North West Cape, Western Australia. Seven model algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA) (Hastie et al. 1994), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as an ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| **Resting** | | | | | | |
|---|---|---|---|---|---|---|
| **Explanatory variables** | | | | | | |
| **Model** | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** |
| ANN$^0$ | 0.66 | **0.76** | 0.09 | 0.00 | 0.00 | 0.03 |
| FDA$^6$ | 0.00 | 0.06 | 0.57 | 0.05 | 0.01 | **0.76** |
| GAM$^9$ | 0.08 | 0.25 | **0.49** | 0.02 | 0.18 | 0.35 |
| GBM$^6$ | 0.09 | 0.12 | **0.42** | 0.14 | 0.18 | 0.24 |
| GLM$^7$ | 0.02 | 0.22 | **0.68** | 0.09 | 0.07 | 0.00 |
| MARS$^8$ | 0.00 | 0.12 | 0.35 | 0.09 | 0.00 | **0.60** |
| RF$^5$ | 0.12 | 0.14 | **0.22** | 0.15 | 0.17 | 0.18 |
| Mean of means | 0.14 | 0.24 | **0.40** | 0.08 | 0.09 | **0.31** |
| Ensemble | 0.05 | 0.15 | **0.43** | 0.08 | 0.10 | **0.38** |

### *4.4.3.3 Travelling*

Most single SDMs for travelling performed well with moderate to good AUC values (AUC values ranged from 0.54 – 0.87, median = 0.73, Figure 2). The ensemble model outperformed all single SDMS for dolphin travelling behaviour with an AUC of 0.95 (Figure 4.2).

The ensemble models detailing probability of occurrence of IP bottlenose dolphins engaging in travelling behaviours in the coastal waters of the NWC revealed a high concentration of travelling down the east side of the NWC (Figure 4.3). Modelling travelling data revealed this behaviour was mostly linked to distance to coast and water depth (Table 4.6). Response curves indicated that travelling was more likely to occur in waters 1000 – 2000 m from the coast and in water depths of 7 – 12 m (see S3.5.3, in Appendix 3 of this thesis).

Areas of high probability of occurrence (>0.81) of dolphins travelling were concentrated at the tip and on the eastern side of the NWC, equally likely both inside and outside the marine park (Table 4.7; Figure 4.3). Most of the cells (66 %) with moderate probability (>0.61- 0.80) of travelling dolphins were inside the NMP and the remaining 34% outside the NMP (Table 4.7, Figure 4.3). Travelling behaviours overlapped with Lighthouse Bay, Point Murat and Bundegi Reef Sanctuary Zones, occurring continuously from Lighthouse Bay Sanctuary Zone to the south-eastern boundary of the study area (Figure 4.3).

**Table 4.6:** Importance of environmental and anthropogenic variables for the single and ensemble species distribution models of travelling Indo-Pacific bottlenose dolphins (Tursiops aduncus) at the North West Cape, Western Australia. Seven model algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA)(Hastie et al. 1994), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as an ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| **Travelling** | | | | | | |
|---|---|---|---|---|---|---|
| **Explanatory variables** | | | | | | |
| **Model** | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** |
| ANN$^{2}$ | 0.72 | **0.86** | 0.12 | 0.09 | 0.03 | 0.15 |
| FDA$^{9}$ | 0.28 | 0.48 | 0.10 | 0.04 | 0.12 | **0.53** |
| GAM$^{9}$ | 0.19 | **0.46** | 0.28 | 0.03 | 0.09 | 0.38 |
| GBM$^{10}$ | 0.11 | 0.20 | 0.11 | **0.32** | 0.24 | 0.22 |
| GLM$^{6}$ | 0.23 | 0.40 | **0.52** | 0.16 | 0.01 | 0.25 |
| MARS$^{7}$ | 0.25 | **0.59** | 0.05 | 0.02 | 0.14 | 0.37 |
| RF$^{8}$ | 0.13 | 0.21 | 0.11 | 0.23 | **0.25** | 0.20 |
| Mean of means | 0.27 | **0.46** | 0.18 | 0.13 | 0.13 | **0.30** |
| Ensemble | 0.27 | **0.47** | 0.16 | 0.11 | 0.13 | **0.29** |

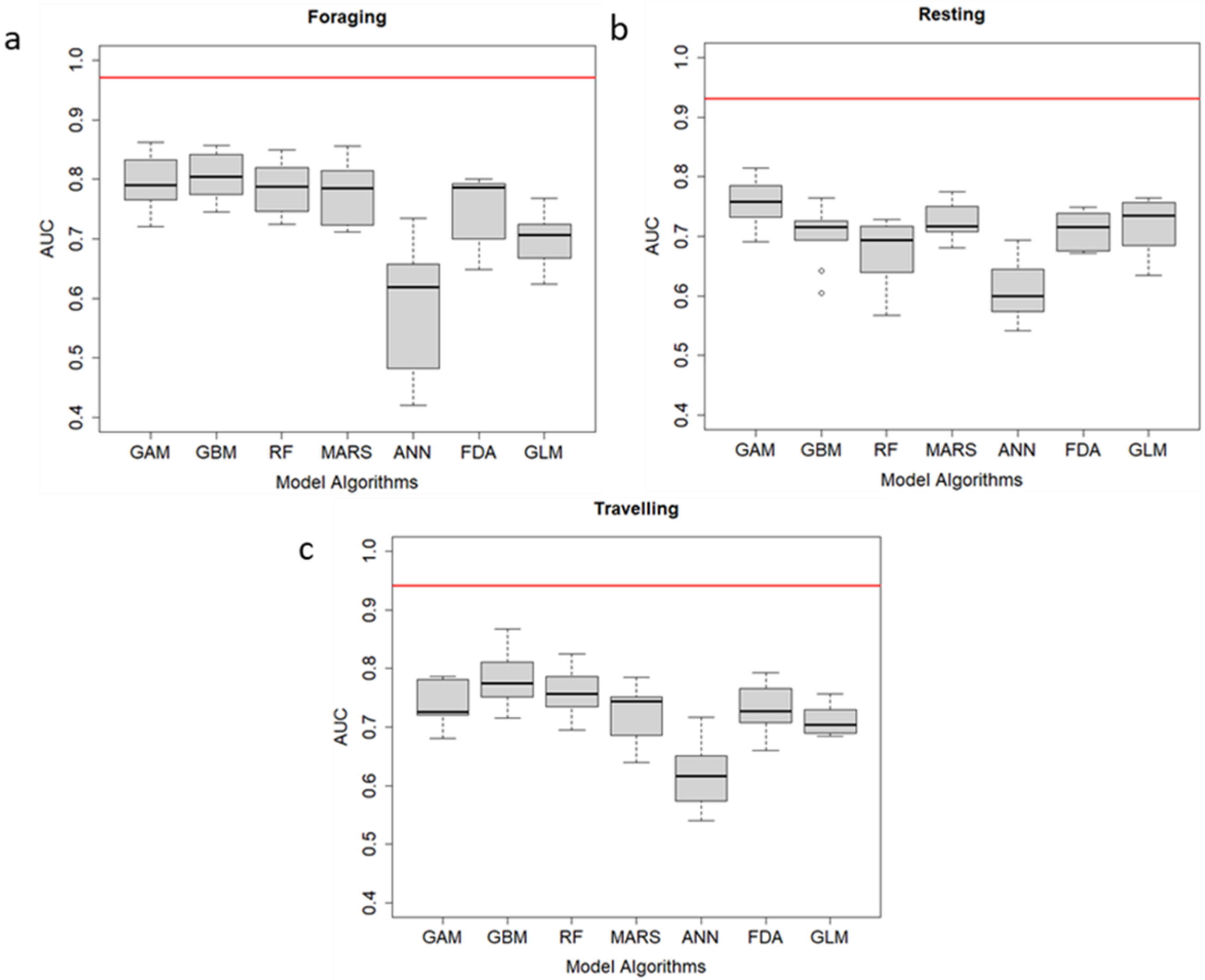
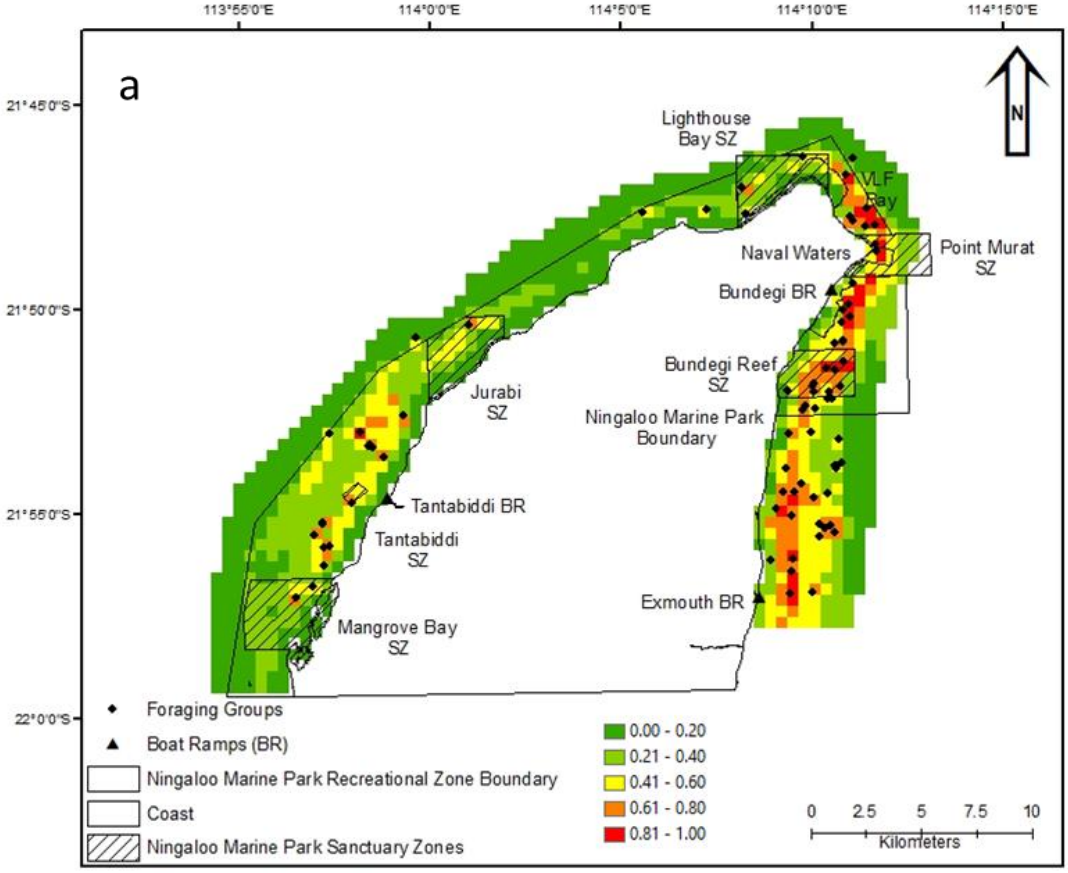


**Figure 4.2:** Performance of species distribution models of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) engaged in a) foraging, b) resting, and c) travelling at the North West Cape, Western Australia. Boxplots for the AUC (area under the curve of the receiver operating characteristic) of the 10-cross validation runs of each modelling algorithm (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis, and GLM: generalised linear model). The red line shows the AUC of the ensemble model. Values of AUC ≥0.7 indicates that the model predictive performance is moderate to excellent.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N
Lighthouse Bay SZ
VLF Bay
Point Murat SZ
Naval Waters
Bundegi BR
Bundegi Reef SZ
Ningaloo Marine Park Boundary
Jurabi SZ
Tantabiddi BR
Tantabiddi SZ
Mangrove Bay SZ
Exmouth BR
Foraging Groups
Boat Ramps (BR)
Ningaloo Marine Park Recreational Zone Boundary
Coast
Ningaloo Marine Park Sanctuary Zones
0.00 - 0.20
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 1.00
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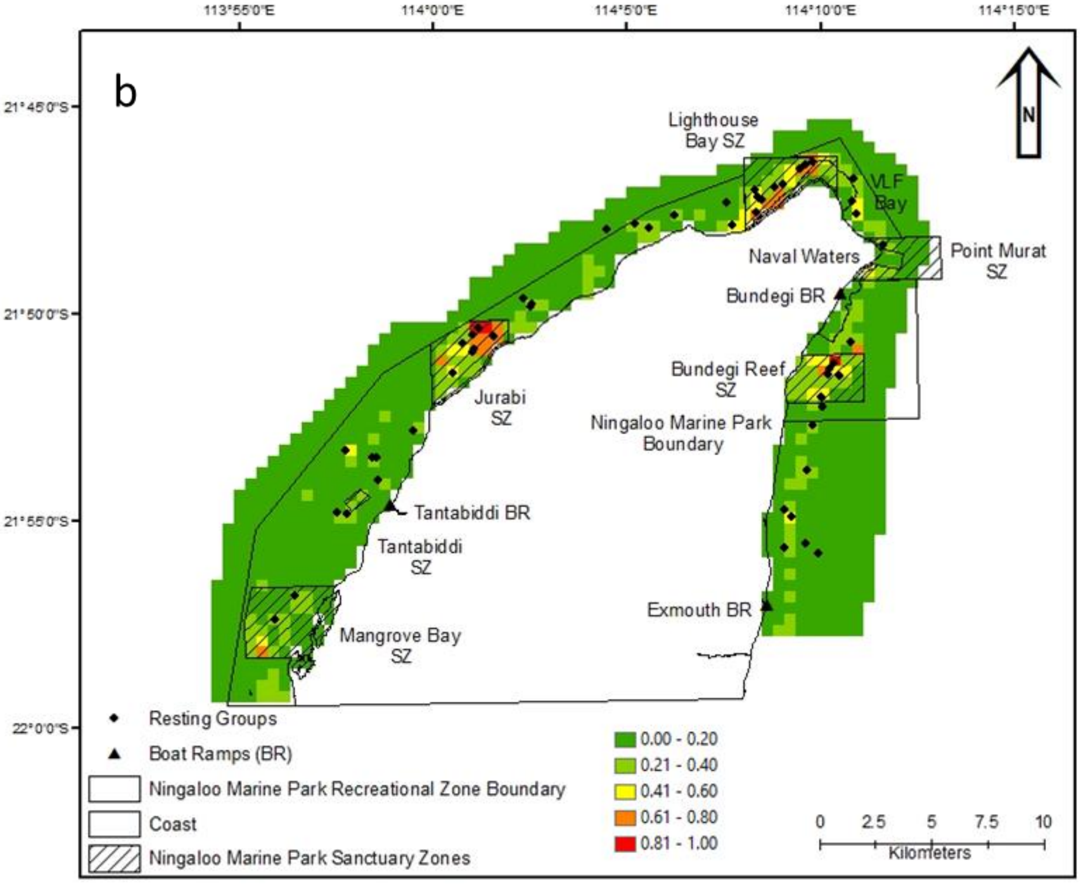
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VLF Bay
Point Murat SZ
Naval Waters
Bundegi BR
Bundegi Reef SZ
Ningaloo Marine Park Boundary
Jurabi SZ
Tantabiddi BR
Tantabiddi SZ
Mangrove Bay SZ
Exmouth BR
Resting Groups
Boat Ramps (BR)
Ningaloo Marine Park Recreational Zone Boundary
Coast
Ningaloo Marine Park Sanctuary Zones
0.00 - 0.20
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 1.00
0
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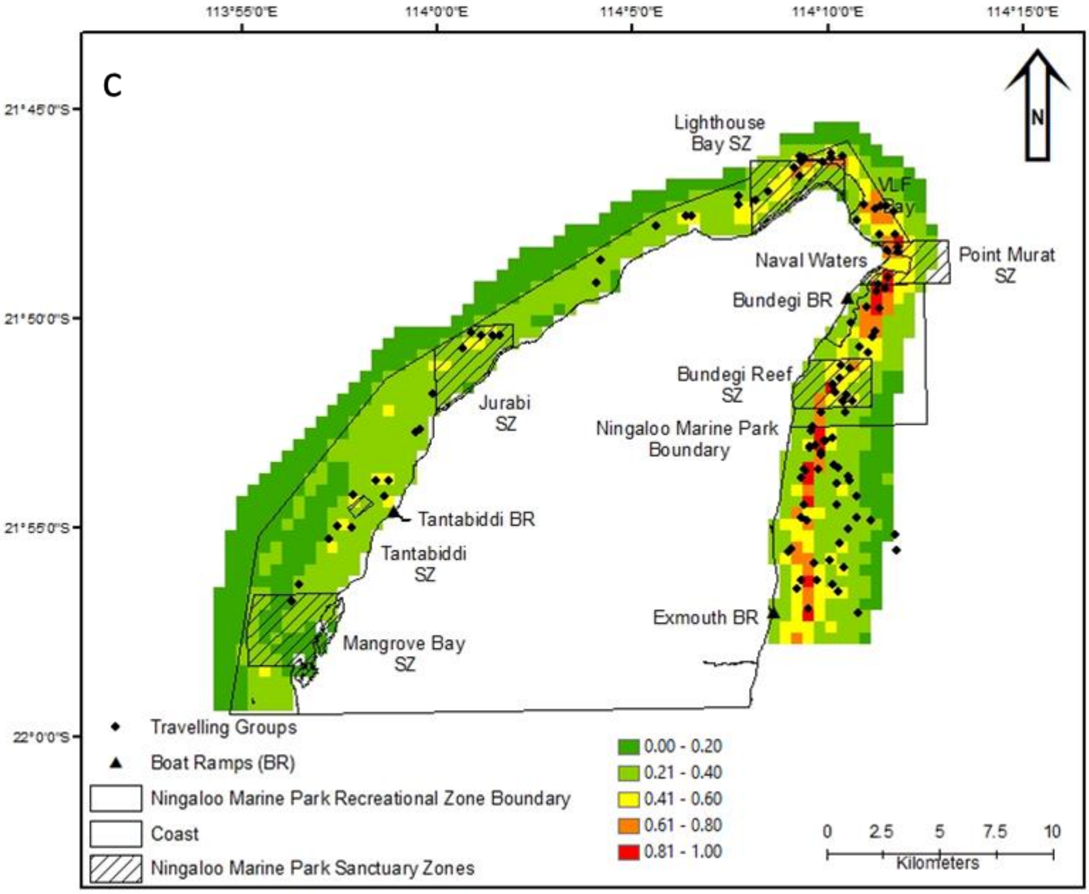

**Figure 4.3:** Ensemble models of the distribution of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) engaged in a) foraging, b) resting, and c) travelling at the North West Cape, Western Australia. Colours as shown in the legend indicate the probability of occurrence 0.00 – 0.40 = low, 0.41 – 0.80 = moderate and 0.81 – 1.00 = high. The Ningaloo Marine Park boundary, Recreational, Sanctuary Zones and boat ramps are marked on the map. Outside the recreational zone boundary is the General Use Zone and the unmarked part of the Point Murat Sanctuary Zone is the area classified as Naval Waters

**Table 4.7:** Number and proportion of cells with high (>0.81), moderate (0.41-0.80) and low (<0.40) probability of Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) occurrence inside and outside the Ningaloo Marine Park (NMP), as well as those cells inside the marine park that fell within designated sanctuary zones (SZ).

| **Behaviour** | **Number of cells inside the NMP** | **Number of cells within the NMP in SZ** | **Number of cells outside the NMP** | **Total number of cells inside and outside the NMP** | **Proportion of cells inside the NMP (%)** | **Proportion of cells in SZ (%)** | **Proportion of cells outside the NMP (%)** |
|---|---|---|---|---|---|---|---|
| High Probability of Dolphin Occurrence (>0.81) | | | | | | | |
| Foraging | 17 | 4 | 6 | 23 | 74% | 17% | 26% |
| Resting | 3 | 3 | 0 | 3 | 100% | 100% | 0% |
| Travelling | 7 | 2 | 7 | 14 | 50% | 4% | 50% |
| Moderate Probability of Dolphin Occurrence (0.41 to 0.80) | | | | | | | |
| Foraging | 136 | 43 | 83 | 219 | 62% | 20% | 38% |
| Resting | 39 | 34 | 1 | 40 | 98% | 85% | 2% |
| Travelling | 90 | 38 | 46 | 136 | 66% | 28% | 34% |
| Low Probability of Dolphin Occurrence (0.00 to 0.40) | | | | | | | |
| Foraging | 597 | 99 | 95 | 692 | 86% | 14% | 14% |
| Resting | 708 | 109 | 183 | 891 | 79% | 12% | 21% |
| Travelling | 653 | 106 | 131 | 784 | 83% | 14% | 17% |
| Total | 750 | 146 | 184 | 934 | N/A | N/A | N/A |

## 4.5 Discussion

Effective conservation and management of species or populations requires a detailed understanding of how behavioural and spatial ecology may influence habitat selection. Ecologically informed decisions about the spatial allocation of conservation actions for highly mobile species such as marine mammals, are facilitated by the identification of key areas within a species range where important behaviours occur (e.g. di Sciara et al., 2016b, Hooker et al., 2011). My study aimed to identify key areas of use and the behavioural processes and environmental and anthropogenic variables related to habitat selection in Indo-Pacific (IP) bottlenose dolphins at the North West Cape (NWC), Western Australia. Further, I used behavioural data to build ensemble species distribution models for specific behaviours (foraging, travelling and resting). Resting behaviours were more localised, occurring in shallow waters (5 – 10 m deep) of designated Sanctuary Zones, whilst foraging and travelling behaviours were more widespread throughout the study area. Foraging was more likely to occur in areas 3000-5000 m from the nearest boat ramp and, over moderate seabed slope gradients (0.4°-0.6°). Travelling was typically more common in deeper waters (7–12 m but likely in waters up to 20 m deep), 1000 – 2000 m from the coast. Waters outside the Ningaloo Marine Park (NMP) were found to be important for foraging and travelling behaviours.

I acknowledge that by pooling all data across the years and seasons my analysis does not consider potential differences across years and seasons in the spatial distribution associated with each behaviour. In addition, my analysis is at the population level and does not take into account individual characteristics such as sex which has been shown to influence habitat selection in other bottlenose dolphin populations (Sprogis et al., 2018a, Fury et al., 2013). Despite these limitations, the results of this study: 1) revealed preferred areas for specific dolphin behaviours that can aid future spatial conservation decisions aimed at improving the protection of important dolphin habitat at the NWC and 2) serve as a platform for future studies assessing differences in habitat preferences according to individual characteristics such as sex.

### *4.5.1 Resting areas for Indo-Pacific bottlenose dolphins at the North West Cape*

In this study, resting hotspots almost exclusively overlapped with relatively shallow (5 - 10 m deep) coastal lagoons and semi-protected bays designated as Sanctuary Zones within the NMP. As the majority of resting hotspots fall within areas likely protected from strong wave action by the Ningaloo Reef or the shape of the coastline, this suggests that these areas may have been selected as a trade-off for energetic benefit. However key resting grid cells are also located in relatively unsheltered waters at the tip of the cape which suggests that not all resting areas have been selected on the basis of shelter from wave action. Engaging in resting behaviour is a high-risk activity for dolphins due to reduced vigilance and it is often hypothesised that dolphins select the safest patches of habitat for this critical behaviour (Heithaus and Dill, 2002, Connor and Heithaus, 1996, Heithaus, 2001a). Water depth and benthic substrate type have also been suggested to be influential in the selection of resting areas, with waters 5-15m deep offering more avenues of escape from predators and, light coloured sandy seafloors making it easier to sight predators, which may camouflage better over macro algae and reef substrates (Heithaus and Dill, 2002). Also, the reduced habitat complexity of bare sandy seafloors, provides less surfaces to interfere with echolocation (Heithaus and Dill, 2002). Resting IP bottlenose dolphins at the NWC showed a preference for waters 5

- 10 m deep; similar to IP bottlenose dolphins in Shark Bay, Western Australia, where predation risk from tiger sharks is high and resting dolphins are mainly found in waters 6 – 12 m deep (Heithaus and Dill, 2002). However, benthic habitat type was not among the most influential predicator variables driving the location of resting hotspots at the NWC (see S3.2.2 in Appendix 3 of this thesis). Instead, resting hotspots occurred over a mix of different substrates; sand, bare reef (subtidal) and coral reef (subtidal) in particular.

Due to risk of predation from tiger sharks in the coastal lagoons in the NMP (Andrzejacek et al., 2019) and killer whales in offshore waters beyond the fringing reef crest (Pitman et al., 2015), I hypothesise that IP bottlenose dolphins at the NWC are regularly selecting the most appropriate habitat to reduce the threat of predation in times of reduced vigilance and increased vulnerability. Furthermore, Sanctuary Zones in the NMP prohibit extractive activities (e.g. recreational fishing) so it is likely that less boat traffic occurs in these areas, thus providing areas with reduced human disturbance to dolphins. Whether these areas have always been important for resting by IP bottlenose dolphins or if they have only become important since marine park zoning began is unknown.

### *4.5.2 Foraging areas for Indo-Pacific bottlenose dolphins at the North West Cape*

The temporal and spatial variation of prey availability and quality of prey have been hypothesised to affect dolphin habitat use (Zanardo et al., 2017, Fall and Skern-Mauritzen, 2014, Eierman and Connor, 2014, Hastie et al., 2004, Degrati et al., 2012, Heithaus and Dill, 2002, O'Donoghue et al., 2010). Foraging activities must provide individuals with sufficient energy to maintain vital functions (i.e. metabolic rate) and support physiological and physical activities (i.e. the costs of travelling, reproduction and thermoregulation) (Spitz et al., 2012). Foraging on mobile prey species comes at an additional energetic cost to individuals, with prey able to travel over large distances and individuals allocating energy to swimming, diving, acoustic searching, herding and the capture of prey (Spitz et al., 2012, Benoit-Bird, 2004). Due to the opportunistic and generalist feeding nature of the bottlenose dolphin (*Tursiops sp.)* (Spitz et al., 2012, Connor et al., 2000)*,* it is hypothesised that IP bottlenose dolphins at the NWC are foraging in locations where either prey density or quality of prey is highest or the nature of the seascape (i.e. seabed slope and oceanographic conditions) is most conducive to capture of prey.

In this study, ensemble models indicated coastal waters at the tip and eastern side of the NWC in Exmouth Gulf are important foraging areas for IP bottlenose dolphins. In addition, the coastal lagoons between Mangrove Bay Sanctuary Zone and Jurabi Sanctuary Zones on the west of the NWC are other suitable foraging area for IP bottlenose dolphins. The coastal waters of the NWC contain a rich biodiversity of teleost fish species with 550 species recorded along the Ningaloo Coast and more than 780 species in the Exmouth Gulf (Fitzpatrick et al., 2019, Hutchins et al., 1996, McLean et al., 2016). Many of the observed fish species (i.e mackerel, mullet, trevally, emperor, snapper and cephalopods; (Fitzpatrick et al., 2019) at the NWC have been found to be important in the diets of other IP bottlenose populations (Amir et al., 2005, Kiszka et al., 2014). Many additional fish species present in these coastal waters are also likely prey sources for these dolphins (e.g. bream, flounder, flathead, whiting and herring; (Fitzpatrick et al., 2019). The close proximity of the continental shelf to the coast influences the seabed slope in this region, a characteristic that has influenced the location of foraging behaviours for other delphinids (Hastie et al., 2004, Shane, 1990, Cafaro et al., 2016). IP bottlenose dolphins were also more likely to forage in areas with moderate sea slope gradient (0.4° - 0.6°). Possible explanations for this include; the nature of the gradient providing an avenue for IP bottlenose dolphins to trap prey against (e.g. as has been observed in killer whales, (Orcinus orca; Heimlich-Boran, 1988) and in bottlenose dolphins (Tursiops truncatus, Torres and Read, 2009)), and therefore, increasing their efficiency of capturing prey. More simply, there may be larger numbers of prey aggregations in these waters (Bailey and Thompson, 2010, Bouchet et al., 2015). The relatively close proximity of the continental shelf to land (i.e. the 200 m depth contour is approximately 10 000 m from the northern end of the Ningaloo Reef; Hearn and Parker, 1988), creating upwellings and highly productive coastal waters, may also explain the higher occurrence of foraging dolphins in waters 1000 – 2000 m from the coast. The NWC region is subjected to strong localised currents, with deeper stratified waters outside the Gulf, mixing with vertically mixed waters from within the Gulf, enhancing productivity of waters at the entrance of the Gulf, near Point Murat (Verspecht, 2002). The enhanced primary productivity at the entrance to the Gulf would provide the basis for bottom-up control of the food web, likely leading to the aggregation of important fish prey species for IP bottlenose dolphins in that area (e.g. Hunt et al., 1998, Santos-Carvallo et al., 2018). However, the diet and foraging ecology of IP bottlenose dolphins in this region is largely unknown and highlights an important avenue for future research in this area.

### *4.5.3 Travelling areas for Indo-Pacific bottlenose dolphins at the North West Cape*

The quality and location of habitat patches has an important effect on the movement patterns of animals (Fortin, 2003). In productive ecosystems, where resources are spatially and temporally predictable, animals generally range over smaller areas in search of prey (Roshier et al., 2008). In comparison, animals which inhabit resource poor environments, where prey is often sparsely distributed, must travel over broader scales to locate the necessary resources (Roshier et al., 2008). Dolphins typically travel between areas of high prey availability and preferred resting locations (Karczmarski et al., 2000, Ribeiro et al., 2007, Viddi et al., 2011). It has been suggested that using optimal habitat patches in close proximity to each other would likely reduce the energetic costs associated with travelling long distances (Thorne et al., 2012). Although widespread throughout the area of my study, travelling behaviours of IP bottlenose dolphins were more likely to occur in the Recreational Zone between Point Murat Sanctuary Zone and Bundegi Reef Sanctuary Zone and outside the NMP. In this area, resting is likely to occur within the Bundegi Reef Sanctuary Zone and foraging more likely to occur in the Bundegi Reef Sanctuary Zone and adjacent waters. The concentration of all three behavioural states in this area, suggests that this particular area of the NWC offers optimal habitat for IP bottlenose dolphins. Specifically, the area provides a productive habitat in which individuals can forage, suitable habitat to rest and replenish energy levels and corridors in which individuals can reduce energetic costs by travelling relatively short distances when moving between these patches.

### *4.5.4 Separation of habitats for different behaviours*

The intrinsic risk of habitat patches, greatly influences selection by individual dolphins for certain behavioural processes (Heithaus and Dill, 2002) and distinct separations between resting and foraging areas have been observed in other dolphin populations (Karczmarski et al., 2000, Keith et al., 2013). In this study, resting hotspots for IP bottlenose dolphins were predominantly located in different locations from foraging hotspots despite similarity in water depths. A possible explanation for this, is that due to the generally heterogeneous nature of the marine environment and associated habitats deemed either ‘safe’ or ‘risky’ by IP bottlenose dolphins, individuals may be opting to put distance between areas of higher risk and more vulnerable activities as a trade-off for fitness benefits. Additionally, the increased turbidity and reduced water visibility in the Exmouth Gulf (personal observations) compared to outside of the Gulf, likely makes it more difficult to sight predators, particularly in times of reduced vigilance. Abrahams and Kattenfeld (1997) have suggested that any antipredator behaviour becomes ineffective in areas of increased turbidity and decreased water visibility. Therefore, the reduced water visibility in the Exmouth Gulf, may explain why these areas, outside the NMP, are not preferred resting habitat for the IP bottlenose dolphins at the NWC.

### *4.5.5 Implications for conservation and management*

Anthropogenic impacts that arise from human presence and activities in coastal environments have been known to influence the distribution of coastal dolphins (Lusseau, 2005, Nowacek et al., 2001, Bejder et al., 2006). A key source of anthropogenic impacts at the NWC is boat traffic and associated recreational and commercial activities. Disruptions to individual dolphins engaged in critical behavioural states such as resting, foraging and travelling, through vessel approaches and underwater noise can have significant consequences for populations (Lusseau and Higham, 2004). Future studies involving NWC IP bottlenose dolphin responses to vessel presence and noise would aid managers in assessing the potential impacts associated with cumulative and repeated exposure to this form of anthropogenic influence.

Boat density is highest within coastal lagoons to the west of the NWC, and within waters from the tip and down the east side of the NWC (Smallwood and Beckley, 2012). Such areas, overlap with key areas for foraging, resting, and travelling for IP bottlenose dolphins. During these behavioural states, dolphins are vulnerable to displacement and disturbance associated with the presence of boat traffic (Lemon et al., 2006, Lusseau, 2003, Stensland and Berggren, 2007). Therefore, managing boat traffic and anthropogenic pressure along IP bottlenose dolphin travelling routes and in foraging and resting hotspots is important to avoid displacement from desirable foraging and resting areas. Further, vessel management is important for the longevity and persistence of this dolphin population in the coastal waters of the NWC. For the Near Threatened population of IP bottlenose dolphins inhabiting coastal waters at the NWC, important resting areas appear to be appropriately managed, as these were almost exclusively located in designated Sanctuary Zones. However, areas of moderate importance for resting also occur near both Bundegi and Tantabiddi boat ramps. Foraging was likely to occur in relatively close proximity to all three boat ramps with the highest probability of foraging occurring adjacent to the Bundegi boat ramp and within Recreational Zones where recreational fishing is permitted (Smallwood and Beckley, 2012, Smallwood et al., 2012), highlighting the vulnerability of individuals engaged in this behaviour to disturbance and competition for food.

Therefore, I suggest to managers that areas in close proximity to boat ramps where resting individuals are likely spending more time at the surface and foraging individuals are likely to be surfacing erratically, should be considered candidate areas for boat ‘go-slow’ zones. Such speed restriction zones have have been implemented in other states of Australia (e.g. South Australia and New South Wales (Steckenreuter et al., 2012a, Adelaide Dolphin Sanctuary., 2014).

Additional Sanctuary Zones and a marine park boundary expansion would also benefit the IP bottlenose dolphin population at the NWC. Current Sanctuary Zones encompass important resting and foraging habitat and there is evidence that fish assemblages within Sanctuary Zones have a higher biomass and abundance than at adjacent sites where fishing activities are permitted (Fitzpatrick et al., 2015). Therefore, an expansion of the Bundegi Reef and Point Murat Sanctuary zones, or the introduction of a Very Low Frequency (VLF) Bay Sanctuary Zone would benefit IP bottlenose dolphin conservation in this region. These proposed zoning changes would encompass majority of the core foraging habitat used by IP bottlenose dolphins. Managers may also consider extending the boundary of the NMP further into the Exmouth Gulf, as this area has been shown to be of importance to foraging groups and an important avenue for dolphin movement.

The important areas identified in this study for foraging, resting and travelling behaviours highlights areas for spatial prioritisation in a region experiencing mixed levels of protection, which would aid the management and conservation of this Near Threatened species. Additionally, with consideration of the ‘sentinel’ and ‘umbrella’ attributes of bottlenose dolphins (Moore, 2008, Bossart, 2011), my recommendations would not only benefit the Near Threatened population of IP bottlenose dolphins at the NWC, but also contribute to the conservation and management of other marine species inhabiting the coastal waters of this region.

# 5 CHAPTER 5: GENERAL DISCUSSION AND THESIS CONCLUSIONS

The Indo-Pacific bottlenose dolphin (*Tursiops aduncus;* hereafter IP bottlenose dolphin) is listed as Near Threatened on the IUCN's Red List (Braulik et al., 2019) and as Data Deficient by the action plan for Australian mammals (Ross, 2006, Woinarski et al., 2014). Furthermore, the species is currently listed as a Matter of National Environmental Significance under the Environmental Protection and Biodiversity Conservation Act (EPBC) because of its status as a migratory species and a cetacean (DoE., 2013, Miller et al., 2018, Bancroft and Sheridan, 2000). As a K-strategist species, with long lifespans and slow rates of maturity; IP-bottlenose dolphins are susceptible to cumulative threats and disturbance in areas experiencing a high degree of human influence (Hawkins et al., 2017, Stensland and Berggren, 2007, Williams, 2014, Bejder et al., 2012).

The species ecology is poorly known across most of the northern tropical coast of Australia, particularly that of north-western Australia, a rapidly changing region with increasing coastal and industrial development and associated human pressures (Bejder et al., 2012, Allen et al., 2012, Bejder et al., 2006), and in close proximity to predicted global hotspots of marine mammal species extinction risk (Davidson et al., 2012). Thus, establishing baseline ecological information for the future management and conservation of this species has been highlighted as a priority by Australia’s Department of the Environment under the Coordinated National Research Framework to Inform the Conservation and Management of Australia’s Tropical Inshore Dolphins (DoE, 2015). This study aimed to fill in gaps of knowledge about the population demography and spatial ecology of Indo-Pacific bottlenose dolphins and improve the basis for their conservation and management in Australian waters.

In this thesis, I used boat-based surveys, photo-identification, and behavioural observations of IP bottlenose dolphins inhabiting the coastal waters off the North West Cape (NWC), Western Australia to: 1) estimate their population demographics (abundance, survival and site fidelity patterns) using a combination of capture-recapture models and site fidelity indexes (Chapter 2; Haughey et al. (2020); 2) assess their spatio-temporal distribution and habitat preferences (Chapter 3), and 3) identify the behavioural processes influencing habitat selection using ensemble species distribution modelling (Chapter 4). In this final chapter (Chapter 5) I summarise the main findings of each of the three data chapters, the implications of these findings, and provide recommendations for conservation, management, and future research directions.

The results of my thesis fill gaps in the knowledge of IP bottlenose dolphin ecology and address research priorities identified by the Australian Commonwealth Government towards the conservation and management of Australia's Tropical inshore dolphins (DoE, 2015). Furthermore, the methodologies used in this thesis offer a strong framework that can be replicated with IP bottlenose dolphin populations elsewhere, but also with other marine and terrestrial fauna where photo-identification and species distribution modelling techniques are feasible. Most importantly, the results have established baseline ecological information on this dolphin population, providing a foundation on which future research can build upon to inform the effective conservation and management of this species.

## 5.1 Coastal waters of the North West Cape are an important area for Indo-Pacific bottlenose dolphins.

Coastal waters of the northern Ningaloo Marine Park (NMP) and Exmouth Gulf within the NWC study area (130km$^2$) are inhabited by a moderately large IP bottlenose dolphin population (311-370 individuals), of relatively high density, with 2.4 to 2.8 dolphins per km$^2$ (Chapter 2). More than 50% of these individuals (229) display low site fidelity to the study area, potentially a result of; prey availability, predation risk, resource partitioning, community structure and exposure to both open oceanic and enclosed protected habitat types (Chapter 2). Within the study area, IP bottlenose dolphins showed a preference for inshore waters (less than 2km from the coast), with areas of high probability of occurrence overlapping with designated sanctuary zones but also occurring outside the boundaries of the NMP (Chapter 3). Also, there were observable seasonal changes in dolphin distribution, likely a response to prey availability and predator avoidance (Chapter 3). Further, results revealed localised areas for resting behaviours and a more widespread distribution of foraging and travelling behaviours (Chapter 4). Collectively, these findings indicate that coastal waters at the NWC and neighbouring waters are of high importance for critical population behaviours and therefore an important area for the conservation of the IP bottlenose dolphin species.

### *5.1.1 Population abundance and site fidelity patterns (Chapter 2)*

Abundance estimates, obtained from photographic capture-recapture analysis, are larger than most other reported estimates for IP bottlenose dolphin populations occupying similar sized study areas (63 to 160 individuals) (Möller et al., 2002, Smith et al., 2013, Brown et al., 2016, Raudino et al., 2018), with the exception of one population in southern Queensland, Australia, reporting 861 to 895 individuals (Chilvers et al., 2003). Additionally, a large proportion of the NWC IP bottlenose dolphin population displayed low levels of site fidelity, with individual site fidelity indexes classifying 58% of individuals as non-resident and a low population site fidelity index score (0.019). Thus, indicating regular turnover of individuals via movement into and out of the study area. Dolphin abundance is typically influenced by habitat type, with protected and enclosed areas often containing smaller populations than those that occupy semi-open habitats (Ballance, 1992, Defran and Weller, 1999, Shane et al., 1986, Wells et al., 1987). In terms of site fidelity, high levels of residency are characteristic of bottlenose dolphins inhabiting protected coastal areas, often with high prey availability and low predation risk (Passadore et al., 2018b, Brown et al., 2016, Chabanne et al., 2012, Dulau et al., 2017, Fury and Harrison, 2008, Webster et al., 2014, Zanardo et al., 2016). In contrast, low residency is often typical of individuals inhabiting areas where ideal habitats vary spatially and temporally (Lafontaine et al., 2017a, Edwards et al., 2009). As the NWC study area offers both protected, enclosed waters (i.e. Exmouth Gulf and coastal lagoons) and semi oceanic waters (i.e. portions of the NWC exposed to the Indian Ocean), access to both open and enclosed habitats within the study area may explain the relatively large population size, particularly of non-resident individuals. Alternatively, resource distribution may be patchy, varying spatially and temporally throughout the study area, and wider region. Despite the low levels of site fidelity observed, the high number of animals (both residents and non-residents) using the study area over time implies that the NWC is an important habitat within the overall home range of IP bottlenose dolphins in this region.

### *5.1.2 Distribution and habitat preferences (Chapter 3)*

Ensemble modelling techniques revealed that the IP bottlenose dolphin spatial distribution at the NWC was mostly explained by distance to coast, followed by distance to boat ramp. Thus, highlighting the importance of nearshore waters for this species near areas of high boat traffic, both inside and outside the NMP. The most influential predictor variables of IP bottlenose dolphin distribution also varied seasonally (autumn: distance to coast and water depth, winter: distance to coast and SST and, spring: marine park zone and water depth). Generally, areas of moderate to high probability of dolphin occurrence were located around the tip of the NWC and extended to the south-eastern boundary of the study area into the Exmouth Gulf. During spring, these areas were mostly outside the Ningaloo Marine Park (NMP), extending from the boundary of the NMP to the south-eastern boundary of the study area. The results are consistent with the nearshore distribution and preference for relatively shallow waters (≤15 m) that has been reported for IP bottlenose dolphins elsewhere (Sprogis et al., 2018a, Vargas-Fonesca et al., 2018, Ansmann et al., 2015b, Heithaus and Dill, 2002).

Overall, I hypothesise that locations of moderate to high probability of occurrence were likely driven by prey availability, with the Exmouth Gulf and Ningaloo Reef home to a rich biodiversity of teleost fish species. Additionally, the presence of predatory tiger sharks (*Galeocerdo cuvier)* in coastal lagoons on the west side of the NWC and; the presence of predatory killer whales *(Orcinus orca)* in offshore waters beyond the fringing reef on the western side of the NWC may also be driving distribution.

### *5.1.3 Behavioural processes underlying habitat selection (Chapter 4)*

Combining behavioural and spatial data through ensemble species distribution modelling revealed key environmental and anthropogenic variables linked to foraging, resting, and travelling behaviours of IP bottlenose dolphins and key areas associated with these behaviours across the NWC. Results of this chapter provide insights into the functional use of preferred habitats. The identified behavioural hotspots highlight key areas for IP bottlenose dolphins at the NWC, providing important information for future spatial planning.

Foraging was explained by distance to boat ramp and seabed slope, with areas of moderate to high probability of occurrence concentrated at the tip of the NWC and in the waters of the Exmouth Gulf. Additionally, coastal lagoons on the west side of the NWC experienced moderate probability of foraging behaviours. Although diet for IP bottlenose dolphins is currently unknown, the location of these hotspots provides insight into important areas for potential aggregations of prey for IP bottlenose dolphins and critical areas for the effective management of this population. The close proximity of the continental shelf to the coast influences the seabed slope in this region, a characteristic that has also influenced the location of foraging behaviours for other delphinids (Hastie et al., 2004, Shane, 1990, Cafaro et al., 2016). In addition, the unique oceanographic conditions (i.e. two opposing current systems; the Leeuwin and Ningaloo currents and mixing of deeper stratified waters with vertically mixed waters from within the Exmouth Gulf) at the NWC likely enhance productivity in the waters near the entrance to the Exmouth Gulf, where the highest probability of occurrence for dolphin foraging was located.

Resting hotspots of IP bottlenose dolphins were mainly located in shallow waters (5 –10 m deep) of Sanctuary Zones, with marine park zone and water depth, the most important variables influencing the location of this behaviour. Engaging in resting is a risky activity for dolphins as reduced vigilance allows individuals to be more susceptible to predation. Therefore, I hypothesise that the IP bottlenose dolphins at the NWC are likely selecting the safest patches for resting, in order to reduce the risk of predation, as has been observed in other populations (Heithaus and Dill, 2002). The positioning of these hotspots in Sanctuary Zones may also be linked to less boat traffic and human activity associated with restrictions in these zones.

The spatial and temporal predictability of prey resources influences the ranging patterns of individuals and communities. In productive ecosystems where resources are spatially and temporally predictable, animals should range over smaller areas in search for food. Comparatively, animals inhabiting resource poor environments, where prey is often sparsely distributed, must travel over broader areas to find the necessary resources (Roshier et al., 2008, Gowans et al., 2007). In my study, the occurrence of travelling IP bottlenose dolphins at the NWC was influenced by distance to coast and water depth. For example, dolphins were more likely to be found travelling in waters 1000 - 2000 m from the coast and in water depths of 7– 12 m. Areas of moderate to high probability of travelling occurrence were widespread but mainly located on the east of the NWC and adjacent to foraging areas. This suggests the coastal waters of the Exmouth Gulf offer a productive environment and that animals in this section of the NWC may not have to range far in search for food.

## 5.2 Implications and recommendations for the conservation and management of Indo-Pacific bottlenose dolphins at the North West Cape

The preference of IP bottlenose dolphins for shallow coastal waters at the NWC highlights the potential vulnerability of individuals to increasing and cumulative anthropogenic stressors associated with nearshore areas. As discussed in chapter 1, the primary anthropogenic impacts and threats faced by IP bottlenose dolphins at the NWC can be grouped into three categories: 1) vessels (disturbance, displacement and boat strike); 2) interactions with fishers and fishing equipment (recreational and commercial), and; 3) increased development and exploration in adjacent waters. Addressing and effectively managing these key threats will greatly contribute to IP bottlenose dolphin conservation in the region. Therefore, below I provide recommendations for future conservation and management of IP bottlenose dolphins in the NWC region based on my PhD research results.

### *5.2.1 Implications and recommendations for addressing threats from vessel traffic*

Displacement, behavioural changes, and boat strike as a result of vessels have been reported in numerous bottlenose dolphin populations (Nowacek et al., 2001, Lusseau, 2003, Buckstaff, 2004, Lusseau, 2005, Lemon et al., 2006, Nowacek et al., 2007, Stensland and Berggren, 2007, Jensen et al., 2009, Steckenreuter et al., 2012b, La Manna et al., 2013, Marley et al., 2017). Species distribution modelling predicted that IP bottlenose dolphins were likely to occur in areas close to the coast and up to 7000 m from the nearest boat ramp (Chapter 3). Also, areas of moderate to high probability of dolphin occurrence overlapped with areas of high boat density (Smallwood et al., 2012). Therefore, it is likely that individuals will come into close proximity of vessels throughout their distribution. Further, it is expected that vessel presence and associated noise may have the potential to cause disturbance to this population, particularly if cumulative over time, as has been observed in other delphinid populations (Bejder et al., 2006, Lemon et al., 2006, Lusseau, 2003, Lusseau, 2005, Nowacek et al., 2001, Stensland and Berggren, 2007).

Faster moving vessels increase the risk of vessel strike, so to reduce this risk and to protect dolphins, speed limits have often been imposed in core areas of use for dolphins in other populations. The location of these populations include the Adelaide Dolphin Sanctuary in the Port River, South Australia (Adelaide Dolphin Sanctuary., 2014); the Sha Chau and Lung Kwu Chau Marine Park, Hong Kong (Jefferson et al., 2009) and; the Port Stephens-Great Lakes Marine Park, New South Wales, Australia (Steckenreuter et al., 2012a). Appropriate placement of these speed limit zones, greatly increases their effectiveness (Steckenreuter et al., 2012a) in reducing the risk of strike, with positive benefits of these zones documented for other taxa (Calleson and Frohlich, 2007, Conn and Silber, 2013, Laist and Shaw, 2006). Therefore, these zones should be placed where individual vigilance is decreased, erratic surfacing behaviour is likely and vulnerable individuals are more likely to spend large periods of time at the surface of the water, and therefore becoming more vulnerable to boat strike or disturbance from boat noise. ‘Go slow zones’ with maximum speeds of 4 knots would be most beneficial in areas in close proximity to boat ramps where core resting, foraging and travelling behaviours are highly likely to occur and density of boat traffic is high (Chapter 4). A more immediate management measure could involve installing signage at boat ramps to educate and alert the public of these key areas whilst recommending slower boat speeds and reminding of minimum approach distances. This information should also be included in marine park brochures.

### *5.2.2 Implications and recommendation for addressing anthropogenic threats from interactions with fishers and fishing equipment (recreational and commercial)*

The NWC is highly regarded as one of the best recreational fishing areas in Australia, with the coastal waters of the NWC containing a rich biodiversity of teleost fish species (Mitchell et al., 2018, Williamson et al., 2006, Sumner et al., 2002, McLean et al., 2016, Fitzpatrick et al., 2019). In a study by Smallwood and Beckley (2012), shore and boat-based recreational fishing were found to occur widely throughout the NMP, overlapping with areas of high to moderate probability of occurrence of IP bottlenose dolphins. Additionally prawn trawling occurs in waters adjacent to the study area, where baseline information on IP bottlenose dolphin abundance and distribution is still missing (Kangs et al., 2006, Kangas et al., 2015).

The Exmouth Gulf Trawl Fishery appears to be relatively well managed, with fitted bycatch reduction devices (BRDs) in trawl nets and daytime fishery closures (08:00 to 18:00 hours). Allen et al. (2014), reported a reduction in the number of dolphin individuals caught as by products in the Pilbara Prawn Trawl Fishery when BRDs were installed and during the time of 00:00 to 05:59 hours. However, the magnitude of this threat to IP bottlenose dolphins in the Exmouth Gulf remains to be evaluated, and detailed research and monitoring into the interactions between this fishery and IP bottlenose dolphins is needed. The implementation of a marine mammal observer program will help evaluate the number of dolphins bycaught (if any) and further reduce the threat of bycatch to IP bottlenose dolphins in the Exmouth Gulf. In Australia, it is illegal to provision free-ranging marine mammals with food under State and Federal law (EPBC Act., 1999) without a license, yet occasionally humans will partake in this activity illegally (Senigaglia et al., 2019). Monitoring recreational fishers at the NWC through regular boat-based education and compliance surveys would encourage correct dolphin interaction behaviours and the correct storage and disposal of fishing equipment. As previously mentioned, an effective management measure could involve installing signage at boat ramps to educate fishers on these topics.

### *5.2.3 Implications and recommendation for addressing anthropogenic threats from increased development and exploration in adjacent waters*

The baseline ecological information on IP bottlenose dolphins presented in this thesis provides a solid platform for future environmental impact assessments (EIAs) for ongoing and upcoming developments (e.g. Subsea 7 pipeline; see Chapter 1) in the NWC region that may pose a threat to the local dolphin population. The NWC represents an important habitat for IP bottlenose dolphins with a large number of individuals using the area (Chapter 2), animals showing a preference for shallow waters close to the coast (Chapter 3), and key foraging, resting and travelling areas associated with these coastal waters (Chapter 4). As current developments in this area have preceded baseline information, using the information presented in this thesis in future EIAs will help evaluate future impacts and risks to the population and develop appropriate mitigation strategies. The research design and analytical framework implemented in this study and the future research directions recommended (see section 5.3 Future research directions) should be considered in future environmental impact assessments at the NWC and adjacent areas.

### *5.2.4 Implications for future management plan and zoning of the Ningaloo Marine Park and adjacent waters.*

The most recent management plan for the NMP (Management Plan Number 52; 2005-2015) recognises the common bottlenose dolphin (*Tursiops truncatus*) as the only species of this genus occurring in the area. This is likely a consequence of the debate and uncertainty surrounding the taxonomy of the species, and a profound lack of baseline knowledge on dolphins at the NWC. Despite IP bottlenose dolphins genetically confirmed to inhabit the coastal waters of the NWC and the NMP (Allen et al., 2012), they are yet to be included in their own right in the management plan of the marine park, even though they have been recognised as ecologically valuable to the NMP. To deliver effective management and conservation outcomes for this population, and the species in future, it is essential that the presence of this Near Threatened species at the NWC supported by information from this thesis is recognised and informs future management plans and marine park zoning of the NMP.

Chapter 2 details the lack of IP bottlenose dolphin residency to the study area, and the NMP. Also, Chapter 3 revealed that although IP bottlenose dolphins were highly likely to occur within designated Sanctuary Zones, but high probability of occurrence was also likely outside the NMP and in the unprotected waters of the Exmouth Gulf. Incorporating functional use into distribution modelling, has highlighted the importance of current marine park Sanctuary Zones for resting and foraging but additionally highlights the moderate to high importance of Very Low Frequency (VLF) Bay for foraging, resting and travelling. Managers should contemplate implementing a Sanctuary Zone encompassing VLF Bay and/or extending the Bundegi Reef or Point Murat Sanctuary Zones to encompass the adjacent Recreational Zone between these two Sanctuary Zones. Waters outside the NMP were also found to be important for foraging and travelling behaviours and contained most of the modelled high probability of occurrence cells during spring months, further supporting a marine park boundary extension to best encapsulate the range of this species at the NWC.

In 2020, using information presented in this thesis, the NWC was included in a large Important Marine Mammal Area (IMMA), extending over the Pilbara Region from Ningaloo Reef further north to the Montebello Islands, WA. Designation of the NWC and surrounding waters as an IMMA will greatly enhance conservation of IP bottlenose dolphins in this region.

A global marine conservation process with specifically developed criteria for application towards the conservation of marine mammals are Important Marine Mammal Areas (IMMAs) (Marine Mammal Protected Areas Task Force., 2016-2020, Corrigan et al., 2014). IMMAs are defined as discrete portions of habitat, important to marine mammal species that have the potential to be delineated and managed for conservation (Marine Mammal Protected Areas Task Force., 2016-2020, Notarbartolo di Sciara and Hoyt, 2020). These areas merit place-based protection and monitoring and work to improve the conservation status of marine mammal species or populations inhabiting these areas (Marine Mammal Protected Areas Task Force., 2016-2020, Notarbartolo di Sciara and Hoyt, 2020). In 2020, using information presented in this thesis, the NWC was included in a large IMMA , extending over the Pilbara Region from Ningaloo Reef to the Montebello Islands, WA.. Designation of the NWC and surrounding waters as an IMMA will greatly enhance conservation of IP bottlenose dolphins in this region.

## 5.3 Future research directions

This thesis provides baseline knowledge on the demographics and spatial ecology of IP bottlenose dolphins inhabiting coastal waters of the NWC. Additional research is required to gain a more complete understanding of IP bottlenose dolphins at the NWC and in the wider region, to accurately determine the impacts of threats and to answer further questions identified in this thesis. Here I present some recommendations for future research into this dolphin population, which would also assist managers in zoning decisions and the implementation of restrictions for subsequent marine park management plans, and fill further knowledge gaps for this species.

### *5.3.1 Identifying the range, distribution, and abundance of Indo-Pacific bottlenose dolphins in the wider region*

This thesis has provided a baseline to build upon, and to comprehensively determine the abundance, distribution, and range of Indo-Pacific bottlenose dolphins in the wider region of north-western Australia. It is clear that many resident and non-resident bottlenose dolphins inhabit the coastal waters off the NWC, suggesting this area, as well as neighbouring waters outside the study area, are of high importance to this species (Chapter 2). Future monitoring of IP bottlenose dolphins in adjacent waters of the Exmouth Gulf and southern Ningaloo Marine Park integrating photo-identification, genetics, telemetry and species distribution modelling would provide further insight into their abundance, movements, population boundaries, site fidelity, habitat use and home range in this region. Such studies would also help to identify areas of potential risk to the dolphins due to human activities.

### *5.3.2 Studies assessing the impact of threats to Indo-Pacific bottlenose dolphins at the North West Cape: the need for long term studies*

In long-lived individuals, such as dolphins, studies spanning over multiple years and generations are needed before trends in population demographic processes and distribution are observable (Clutton-Brock and Sheldon, 2010). Continual long-term monitoring of IP bottlenose dolphins in the NWC is required as a high priority to identify any changes or reductions in population size, site fidelity patterns and range that may occur with time due to anthropogenic and or environmental disturbance (Cagnazzi et al., 2020, Sprogis et al., 2018b)

Vessel traffic, fishing activities and noise from anthropogenic activities are potentially major threats to IP bottlenose dolphins at the NWC. Therefore, future studies aimed at assessing the risks and associated impacts from vessels, noise and fishery interactions are critical next steps for the conservation and management of IP bottlenose dolphins in the NWC region. Quantitative assessments of the interaction IP bottlenose dolphins have with the Exmouth Prawn Trawl Fishery and the level of overlap between dolphin distribution and trawling area are needed. Another avenue for research should include the response of individuals to vessel presence and noise. Such assessments will allow managers to determine key areas of impact and identify the degree of susceptibility of individuals to anthropogenic impact within these areas and manage the population accordingly.

### *5.3.3 Population genetic structure*

Anthropogenic driven change (i.e. habitat degradation and fragmentation, depletion of food sources and disturbance) and climatic events which induce population declines are an increasingly common threat to biodiversity (Bicknell et al., 2012). Coastal dolphin life history traits make them particularly vulnerable to such declines, and therefore knowledge on effective population size, population connectivity and dispersal is critical for effective management (Parra et al., 2019). In the face of these declines, genetic diversity is important for population resilience and persistence, with populations experiencing low genetic diversity at higher risk of extinction (Parra et al., 2019). Habitat selection and local adaptations to environmental conditions and resource availability can shape population structure over small spatial scales (Möller et al., 2007, Wiszniewski et al., 2010). Understanding population structure (i.e. population sub-divisions and connectivity) allows managers to determine the relevant biological units for conservation (i.e. evolutionary significant units (ESUs) or management units (MUs); Fruet et al., 2014). Future studies should include the collection of genetic data from individuals at the NWC to identify genetic diversity, gene flow, effective population size, population structure and to determine MUs at the NWC (i.e. demographically distinct sub-populations that should be managed as separate entities to ensure the viability of a larger metapopulation). Given IP bottlenose dolphins display low site fidelity to the study area and therefore range outside these boundaries, such information will allow managers to determine population boundaries and population connectivity within the wider region.

### *5.3.4 Social structure*

Biopsy sampling of live animals in combination with molecular analysis can also contribute to understanding the social structure of population. Social network analysis describes relationship patterns, individual levels of connectivity and group structure which can answer a variety of ecological questions regarding the social behaviour of individuals (Lusseau et al., 2006), familial bonds (Diaz-Aguirre et al., 2018, Diaz-Aguirre et al., 2019), foraging specialisations (Chilvers and Corkeron, 2001, Methion and Lopez, 2020, Machado et al., 2019), habitat utilisation (Rossbach and Herzing, 1999, Titcomb et al., 2015) and strategies for reproductive success (i.e. potential male-male, male-female or female-female alliances) (Connor et al., 2001, Wiszniewski et al., 2012). Understanding such ecological questions and the social structure of populations is an important component in species ecology, conservation and management.

### *5.3.5 Importance of the North West Cape for breeding, calving and rearing of young*

For coastal dolphins, the ocean poses a challenging environment for raising infant young, with mothers required to maneuver with their young to forage and avoid predators whilst lactating and providing protection to offspring (Teixeira et al., 2018, Mann and Smuts, 1999). Infancy is the most vulnerable period in a mammal's life, with young often handicapped by their small body size, poorly developed survival skills and dependence on their mothers (Mann and Watson-Capps, 2005, Ross, 2001). It is not unlikely that mothers might provide specific strategies of care to maximise offspring survival during the critical period of infancy when mortality risks are higher (Teixeira et al., 2018, Whitehead and Mann, 2000). Differences in habitat preferences and behaviour of females with and without offspring have been observed in several mammalian species (Main et al., 1996, Walker et al., 2006, Pinard et al., 2012, Craig et al., 2014, Ciuti et al., 2005). Several reasons for this have been hypothesized; predator avoidance, limitations in offspring mobility, access to better food resources and avoidance of harassment by males seeking mating opportunities.

Birthing periods and subsequent periods of time where larger numbers of vulnerable mother-calf pairs are likely to be present in an area have been described to range from year-round to seasonal windows (Felix, 1994, Urian et al., 1996, Kasuya et al., 1997, Fernandez and Hohn, 1998, Thayer et al., 2003, Fearnbach et al., 2012, Henderson et al., 2014, Robinson et al., 2017). Identifying birthing periods, habitat preferences and the behavioural ecology of these groups can aid managers in determining important areas for the reproductive success of IP bottlenose dolphins at the NWC.

### *5.3.6 Sex and individual specific habitat use and home range*

The sex of individual IP bottlenose dolphins has been shown to influence habitat selection (Sprogis et al., 2018a, Fury et al., 2013). Home ranging patterns also differ with sex of individuals, with males typically ranging further than females searching for prey or mating opportunities (Sprogis et al., 2016b, Randic et al., 2012, Watson-Capps, 2005). Future species distribution models and home ranging studies incorporating sex data would be beneficial to discern if habitat use and ranging patterns at the NWC are influenced by sex. Biopsy sampling of live animals in combination with molecular analysis should be implemented to determine the gender of individual bottlenose dolphins inhabiting coastal waters of the NWC.

Photo-identification methods could also allow for a more specific habitat use analysis comparing the space use of resident and non-resident individuals identified in Chapter 2. Thus, determining what particular resource (i.e. prey or mating opportunities) may be attracting non-resident individuals to the NWC and the importance of the NWC to these individuals.

### *5.3.7 Diet and predation risk*

Bottlenose dolphin distribution is often the result of a tradeoff between predation pressure and prey availability (Heithaus and Dill, 2002, Heithaus, 2001b, Sprogis et al., 2018c, Smith et al., 2018, McCluskey et al., 2016). Future studies looking into the diet of IP bottlenose dolphins in the NWC, and assessments of prey availability and predation pressure in the region are needed to assess the degree of influence these have on the observed dolphin distribution. Data on potential dolphin prey availability could be obtained through sampling of foraging hotspots using beach seines, gillnets, and Antillean Z-traps (Chapter 4). This could be integrated with stable isotope and fatty acid analysis of biopsy samples from dolphins and tissue samples from potential prey, to gain a more accurate picture of dolphin diet at the NWC, which has been successfully implemented in studies on a range of taxa, including dolphins (e.g. Kiszka et al., 2014, Ferreira et al., 2017, Williams et al., 2014). Information on the likelihood of encountering a predator and therefore, predation risk could be obtained through Baited Remote Underwater Video Surveys (BRUVS) in shallow coastal lagoons (e.g. Espinoza et al., 2014) or through acoustic monitoring (e.g. Braccini et al., 2017, Riera et al., 2019).

## 5.4 Conclusions

This thesis provides a robust baseline of population demographics, distribution, habitat use and behavioural processes underlying habitat selection of the IP bottlenose dolphin population at the NWC. My research has greatly improved the scientific knowledge behind this species and addressed research priorities detailed by the Australian Commonwealth Government towards their conservation and management. The three data chapters included in this thesis indicate the NWC is an important habitat for IP bottlenose dolphins and an area of high conservation significance for this Near Threatened species. The NWC is home to many resident and non-resident bottlenose dolphins suggesting this area, as well as neighbouring waters outside my study area, are of high importance to this species (Chapter 2). This study also highlights that the spatial distribution of these animals at the NWC is linked strongly to inshore areas (Chapter 3) and that the underlying selection of these areas is driven by foraging, resting and travelling behaviors (Chapter 4). The preference of IP bottlenose dolphins for shallow coastal waters and their reliance on these areas for important behaviors such as foraging and resting emphasises the potential vulnerability of this species to increasing and cumulative anthropogenic stressors associated with shallow nearshore waters. Therefore, I suggest for managers to implement ‘go slow’ zones in areas of key biological importance (i.e. foraging, resting, and travelling) that overlap with high boat traffic and, consider information presented here in future rezoning of the NMP. Such rezoning should include the addition of sanctuary zones and extension of the marine park boundary into the Exmouth Gulf to fully encompass key habitats and manage the impacts of anthropogenic influence in this region. Additionally, considering the ‘sentinel’ and ‘umbrella’ attributes of bottlenose dolphins (Moore, 2008, Bossart, 2011), the recommendations made here would not only benefit IP bottlenose dolphins at the NWC, but also contribute to the conservation and management of other marine species inhabiting the coastal waters of this region. The NWC provides an accessible and ideal study site to continue future research and monitoring of the IP bottlenose dolphin population, with generally ideal weather conditions throughout a large portion of the year, the large numbers of individuals using the area and its recent Important Marine Mammal Area (IMMA) nomination. With the Ningaloo Marine Park already established as regulatory framework and baseline information on the species now accessible, a solid platform is available for future research and future conservation and management actions that will benefit this Near Threatened species.

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# 7 APPENDIX 1: SUPPORTING INFORMATION FOR CHAPTER 2

## 7.1 S1.1: Photo scoring protocol

Images were examined and scored according to different quality criteria including clarify, contrast, angle, partial and proportion. Clarity refers to the sharpness of an image and is related to the focus of the image. Contrast refers to the range of tones in the image. Angle takes into account the position of the fin relative to the camera. Partial refers to how much of the dorsal fin is visible in the image and Proportion looks at the size of the fin in the image. Each image is assigned a score for each criterion. A breakdown of the scoring for these four categories is provided in Table 7.1. Clarity and Angle can be excellent, good or poor whilst Contrast, Partial and Proportion can only be excellent or poor. The total Quality (Q) score of each image was determined by summing the score of each category, with images scoring 6-7 classed as excellent, 8-11 as good, and >12 as poor. The distinctiveness of each fin was also assessed according to three categories – D1, D2, D3, where; D1 – Highly distinctive fin (Missing tops, large notches or nicks, animal is very easily identifiable), D2 – Moderately distinctive (A single distinctive feature or multiple small nicks or notches) and D3 – Clean fin (no distinctive features on dorsal fin, it is not possible to identify animal from photographs).

**Table 7.1:** Breakdown of scoring criteria for each of the scorable aspects of a photo identification image**.**

| Criteria | Excellent | Good | Poor |
|---|---|---|---|
| Clarity | 2 | 4 | 9 |
| Contrast | 1 | N/A | 3 |
| Partial | 1 | N/A | 8 |
| Angle | 1 | 2 | 8 |
| Proportion | 1 | N/A | 5 |

## 7.2 S1.2: Summary of POPAN models

**Table 7.2:** AIC Summary of POPAN models fitted to the capture histories of the North West Cape Indo-Pacific bottlenose dolphins to estimate super-population size (N), survival (phi), probability of entry to the population (pent) and capture probability (p). The most supported model is shown in bold. (·) indicates the given parameter was kept constant and (*t*) indicates the given parameter was set as time varying.

| Model | Rank | AICc | Delta AIC | AIC weight | No. Parameters |
|---|---|---|---|---|---|
| **Phi(*t*) p(*t*) pent(.)** | **1** | **696.5697** | **0.0000** | **0.63131** | **13** |
| Phi(·) p(*t*) pent(*t*) | 2 | 698.9764 | 2.4067 | 0.18951 | 13 |
| P(t) Phi(*t*) pent(*t*) | 3 | 699.2729 | 2.7032 | 0.16340 | 17 |
| Pent(*t*) p(.) phi(t) | 4 | 703.9558 | 7.3861 | 0.1572 | 12 |
| Phi(.) p(·) pent(t) | 5 | 715.0253 | 18.4556 | 0.00006 | 8 |
| Phi(t) p(.) pent(.) | 6 | 738.3472 | 41.7775 | 0.00000 | 8 |
| Phi(.) p(.) pent(.) | - | Convergence not reached | N/A | N/A | 4 |
| P(*t*) phi(·) pent(·) | - | Convergence not reached | N/A | N/A | 9 |

**Table 7.3:** QAIC summary of POPAN models fitted to the capture histories of the North West Cape Indo-Pacific bottlenose dolphins to estimate super-population size (N), survival (phi), probability of entry to the population (pent) and capture probability (p). The most supported model is shown in bold. (·) indicates the given parameter was kept constant and (*t*) indicates the given parameter was set as time varying.

| Model | Rank | QAICc | Delta QAICc | QAICc weight | No. Parameters |
|---|---|---|---|---|---|
| **Phi(t) p(*t*) pent(.)** | 1 | 309.5652 | 0.0000 | 0.40220 | 13 |
| Pent(*t*) p(t) phi(·) | 2 | 310.5807 | 1.0155 | 0.24206 | 13 |
| P(·) Phi(.) pent(*t*) | 3 | 311.1908 | 1.6256 | 0.17842 | 8 |
| Phi(*t*) p(.) pent(*t*) | 4 | 311.4348 | 1.8696 | 0.15793 | 12 |
| Phi(*t*) p(t) pent(t) | 5 | 315.7682 | 6.2030 | 0.01809 | 17 |
| Phi(t) p(.) pent(.) | 6 | 321.0312 | 11.4660 | 0.00130 | 8 |
| Phi(·) p(·) pent(·) | - | Convergence not reached | N/A | N/A | 4 |
| P(*t*) phi(·) pent(·) | - | Convergence not reached | N/A | N/A | 9 |

The parm specific link function and 2nd part variance estimation were used to generate these models; Link functions for *p* and *phi* were set to *sin* and *N* was set to log. When time varying, *Pent* was set to *Mlogit(1)*.

## 7.3 S1.3: Summary of MLE transient models

**Table 7.3:** Summary of the MLE transient model (Conn et al., 2011) fitted to the capture histories of the North West Cape Indo-Pacific bottlenose dolphins to estimate super-population size and resident population size. The most supported model is shown in bold. P represents capture probability, π represents entry probabilities, · indicates a given parameter was kept constant and *t* represents a given parameter was time varying.

| Model | AICc | No. of Parameters |
|---|---|---|
| P (t) π (.) | **1234.001** | **7** |
| P (t) π (t) | 1234.902 | 12 |
| P (.) π (t) | 1293.324 | 7 |
| P (.) π (.) | 1308.030 | 2 |

## 7.4 S1.4: Validation of model assumptions

To test the assumption that the population was open I used the two closure tests run in the CloseTest software **(Stanley and Burnham, 1999, Otis et al., 1978)**. RELEASE and U-CARE tested the capture histories for heterogeneity in capture probabilities and for a transient effect. I also tested for any difference in the expected time of first recapture between ‘new’ and ‘old’ individuals captured at any occasion and then seen again at least once. POPAN models assume: (1) all individuals (marked and unmarked) have equal probability of being captured within a sampling period, (2) all individuals have equal probability of survival, (3) marks are unique, permanent and identified correctly, (4) sampling is instantaneous, and (5) the study area remains constant (Pollock et al., 1990). In my study, if an individual (marked or unmarked) is within the study area and breaks the surface of the water during survey, they both have an equal chance of being seen so I deemed this assumption true. I found assumptions 2 and 3 biologically and ecologically true. Assessing the design of my study, assumptions 4 and 5 are also true. The MLE transient model assumes: (1) the population is composed of both resident and transient individuals, (2) transients have the same encounter probability as residents immediately after entering the study area, and (3) transients have a ‘one sample availability’, so any individual sampled more than once is termed ‘resident’ and transients are only in the study area for one sampling period (Conn et al., 2011). The model assumes a strict dichotomy of two groups: residents and transients, which may not be appropriate for all study populations, but was deemed a suitable assumption for this population due to the high proportion of individuals only seen once. To reduce the likelihood of transient individuals being sampled in more than one sampling occasion, sampling intervals should be spaced far enough apart (Conn et al 2011). With a minimum of

23 days between sampling periods, I feel the study design has reduced the potential for transients to be sampled in more than one sampling period, meaning individuals sampled in two or more occasions are more than likely to be resident individuals.

# 8 APPENDIX 2: SUPPORTING INFORMATION FOR CHAPTER 3

*S2.1: ODMAP checklist*

# – ODMAP Protocol –

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## S2.1.1 Overview

*Authorship*

Modelling the distribution and habitat preferences of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) inhabiting coastal waters with mixed levels of protection.

Contact : rebecca.haughey@flinders.edu.au

*Model objective*

Model objective: Mapping and interpolation

Target output: To understand the distribution patterns, habitat preferences and to identify areas of high probability of occurrence for Indo-Pacific bottlenose dolphins at the North West Cape.

*Focal Taxon*

Focal Taxon: Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)

*Location*

Location: North West Cape, Western Australia

*Scale of Analysis*

Spatial extent:

Universal Transverse Mercator zone 50 south based on the WGS 1984 datum

Top: 7591027.338288 m

Left: 17672.044127 m

Right: 211672.044127 m

Bottom: 7565027.338288 m

Spatial resolution: 500m by 500m

Temporal extent: 5 years (2013, 2014, 2015, 2018 & 2019)

Boundary: Rectangle

*Biodiversity data*

Observation type: Field survey

Response data type: Presence/absence

*Predictors*

Predictor types: Habitat, topographic and environmental

*Hypotheses*

Hypotheses: A number of environmental and anthropogenic variables have been shown to influence the distribution of cetaceans, in particular dolphins. I used measures of water depth, seabed slope, sea surface temperature, distance to coast, distance to the nearest boat ramp and marine park zone as predictor variables for Indo-Pacific bottlenose dolphins. I also modelled temporal changes by year and the influence of benthic habitat type within the Ningaloo Marine Park.

### *Assumptions*

Model assumptions: 1. Relevant ecological drivers of species distribution are included 2. Detectability does not change across transects 3. Species are at equilibrium with their environment 4. Sampling is adequate and representative (and any biases are accounted for/corrected)

### *Algorithms*

Modelling techniques: glm, mars, ann, gam, fda, gbm, randomForest

Model averaging: I combined model algorithms to form an ensemble model/prediction.

### *Workflow*

Only weakly correlated explanatory variables were included in the final models. Ensemble predictions were derived using means from model runs that performed well from the single model algorithms.

### *Software*

Software: Analyses were conducted in R Studio using the biomod2 package (https://cran.r-project.org/web/packages/biomod2/index.html, https://github.com/biomodhub/biomod2). Additional packages required were raster, sp and rjava

ArcMap version 10.7 (ESRI) was used to create spatial layers of response (dolphin presence-absence) and predictor variables.

Code availability: Code is available on request

Data availability: Data are available on request

### S2.1.2 Data

*Biodiversity data*

Taxon names: Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)

Ecological level: Population/species

Data sources: Survey data was collected in the field over a 5 year period. Each field season (total = 5) was intensive and lasted 6 months, spanning over the austral seasons of autumn, winter and spring.

Sampling design: Boat based surveys searching for IP bottlenose dolphins were conducted onboard a 5.6 m vessel during the hours of 0700 and 1800 from May to October in 2013, April to October in 2014, May to October in 2015 and April to September in both 2018 and 2019. Sampling periods spanned the Austral seasons of Autumn (March - May), Winter (June - August) and Spring (September – November). Surveys were conducted in favourable weather conditions (i.e. Beaufort Sea State of ≤3 and no rain) and followed a systematic line transect layout (2 x 93 km opposing zig zag lines and 1 x 13 km single line) covering a wide range of habitats, human use areas and environmental variables within the study area.

Sample size:

Over the five years of study, almost 723 hours of survey effort were completed. Survey effort varied slightly between years and austral seasons due to variability in weather conditions. Overall, the highest survey effort and number of dolphin sightings occurred, during the winter months (June-August). In total, we encountered 323 groups of IP bottlenose dolphins, with 70 seen in autumn, 184 in winter and 69 in spring. Overall, 227 (70%) of these groups were seen inside the NMP and 96 (30%) outside these boundaries.

Clipping: All data covered the extent of the study area.

Scaling: 500m x 500m grid resolution.

Absence data: Each 500 m x 500 m grid within the survey area was assigned either a 1 (dolphin presence) or 0 (dolphin absence). In order to reduce false absences (i.e. determining an absent cell when individuals may in fact occur in that area), absence cells were defined based on areas which had the highest survey effort (Phillips et al. 2009). Survey effort was quantified using the total area of ‘on-effort’ survey tracks within each 500 x 500 m grid cell. A 250 m buffer area either side of each transect line was added, which was considered to be the average distance from the vessel that dolphins could reliably be observed under a variety of sea conditions (Zanardo et al 2017, Hunt 2018).Grid cells were then ranked and cells containing no dolphin presence and values of survey effort higher than the mean were considered most likely to represent true absences and therefore were defined as absence cells (Zanardo et al. 2017, Hunt 2018, Passadore et al. 2018).

### *Data partitioning*

Training data: A random data splitting procedure of 75/25% was used for model calibration and testing. We implemented a 10-fold cross-validation method

Validation data: see training data

### *Predictor variables*

Predictor variables: Predictor variables used to model IP bottlenose dolphin distribution and habitat use were classified as: abiotic (i.e. water depth, slope, sea surface temperature (SST) and distance to coast), and anthropogenic (i.e. distance to boat ramp and marine park zone).

Data sources: Most data was collected in situ or calculated using the euclidean distance and cost distance tools in ArcMap. Marine park zoning data was obtained from the Western Australian Government’s Department of Biodiversity, Conservation and Attractions.

Spatial extent:

Top: 7591027.338288 m

Left: 17672.044127 m

Right: 211672.044127 m

Bottom: 7565027.338288 m

Spatial resolution: 500m x 500m

Coordinate reference system: All spatial layers were projected to Universal Transverse Mercator zone 50 south based on the WGS 1984 datum

Temporal extent: 6 month sampling periods repeated over 5 years (2013, 2014, 2015, 2018, 2019)

Temporal resolution: Years and austral seasons

Data processing: SST raster layers were created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size). Slope was calculated as the standard deviation of the depth and complexity as the standard deviation of the slope. Distance to the coast and boat ramps was measured using the Euclidean distance (i.e. shortest straight-line distance) and Cost distance (the shortest distance factoring in land given study area wraps around a peninsula) functions, respectively, using the Spatial Analyst extension in ArcMap. To evaluate the relevance of the marine park zoning for the conservation of IP bottlenose dolphins within the study area, a raster of marine park zones was created with the following zones; General, Recreational, Sanctuary, Special purpose, Naval waters and outside the NMP.

Errors and biases: Prey availability data is not known, but selected predictor variables have been used as proxies for prey availability/distribution.

*Transfer data*

ArcMap version 10.7 (ESRI) was used to create spatial layers of response (dolphin presence-absence) and predictor variables at a 500 x 500 m grid resolution (See Table 8.1, also see *Methods: Predictor variables* section – Chapter 3 of this thesis). All spatial layers were projected to Universal Transverse Mercator zone 50 South.

**Table 8.1: List of predictor variables used in species distribution modelling of Indo-Pacific bottlenose dolphins in the coastal waters of the North West Cape, Western Australia, their associated data source and how they were derived in ArcMap. Each variable was sampled at 500m by 500m resolution.**

| Type of variable | Predictor variable | Variable abbreviation | Data Source |
|---|---|---|---|
| Abiotic | Distance to coast | N/A | Derived using the Euclidean distance tool (Spatial Analyst toolbox). |
| Abiotic | Slope | Slope | Derived using the Slope tool and is measured in decimal degrees (Spatial Analyst toolbox). |
| Abiotic | Sea surface temperature | SST | Derived from *in situ* measurements of SST. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size)(Spatial analyst toolbox). |
| Abiotic | Water depth | Depth | Derived from *in situ* measurements of depth. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst toolbox). |
| Abiotic | Water visibility | N/A | Derived from *in situ* measurements of water visibility using a secchi disk and calculated as a proportion of the total depth. |

| | | | |
|---|---|---|---|
| | | | Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst Toolbox). |
| Anthropogenic | Distance to boat ramp | N/A | Exmouth, Bundegi and Tantabiddi boat ramps are established vessel launch sites in the study area. Derived using the Cost distance tool (Spatial Analyst toolbox) and the coast shapefile as the cost surface. |
| Anthropogenic | Marine park zone | NMP Zone | A NMP zoning shape file which shows the zone boundaries was obtained from the Western Australian Government Department of Biodiversity, Conservation and Attractions service. Each grid cell was assigned a variable according to MP zone using the polygon to raster tool (1=General Use, 2=Recreational, 3=Sanctuary, 4= Special Purpose, 5 = Naval Waters, 6 = outside the NMP) (DPaW. and DoF., 2014) |
| Biotic | Benthic habitat type | Habitat | Benthic habitat data only exists for the Ningaloo Marine Park portion of the study area (Figure 1). This data was derived from a broad scale benthic habitat study of the NMP (DPaW., 2006, Lucieer et al., 2017, Bancroft and Sheridan, 2000). Habitat type was classified as either 1=mobile sand, 2=mangroves, 3=bare reef (intertidal), 4=coral reef (intertidal), 5=bare reef (subtidal), 6=macro algae (subtidal), 7=coral reef (subtidal), 8=saltmarsh and 10=pelagic (No habitat type associated with a value of 9 (mudflat) is present in this section of the NMP). For habitat type definitions, see S2.3 (Appendix 2), Table S3. Each grid cell was assigned a variable according to habitat type using the polygon to raster tool. |

### *S2.1.3 Model*

#### *Multicollinearity*

Before running the SDM's, I tested for collinearity between our continuous numerical explanatory variables using stepwise procedures within the usdm package in RStudio (Naimi, 2015). Variance inflation factors (VIF) were calculated for all variables. Variable pairs with a maximum linear correlation greater than the threshold (0.7) were identified using 'vifcor' and the variable with the highest variance inflation factor (VIF, threshold = 3) was excluded using 'vifstep' (Zuur et al., 2010). These procedures were repeated until there was no variable remaining with a correlation coefficient greater than 0.7 and no variables with a VIF greater than the threshold (Naimi et al., 2014).

#### *Model settings*

See S2.4 in Appendix 2 for model settings.

#### *Model estimates*

The importance of explanatory variables was calculated using a 10-permutation run randomisation procedure within BioMod2 (Thuiller et al., 2009). This procedure allows for a direct comparison between model algorithms and calculates the Pearson's correlation between the standard predictions and predictions where 1 variable has been randomly permutated. High correlation (i.e. little difference between the two predictions) indicates that the variable is not important in the model, and a low correlation indicates that the variable is important. Variables are ranked from 0 to 1 according to the mean correlation coefficient, with the variable with the highest ranking the most influential and the lowest, the least influential (Thuiller et al., 2009).

### *Analysis and Correction of non-independence*

To ensure independence of data points in the face of bottlenose dolphins exhibiting flexible grouping patterns, termed fission fusion (Wells et al., 1987), only the locational point where the initial group members were first encountered whilst on transect was included in analysis.

### *Threshold selection*

To compare modelling algorithms and for comparability with other studies, I used the AUC metric which has been standard and widely used in many SDM studies (Fielding and Bell, 1997). Values of AUC range from 0 to 1; with values >0.5 indicating that the model predictions perform better than random, whereas values <0.5 indicates that the model predictions are no better than what would be expected by chance. In general, AUC values of 0.5–0.7 are considered low and represent poor model performance, values of 0.7–0.9 are considered moderate to good, and values above 0.9 represent excellent model performance (Peterson et al., 2011).

## S2.1.4 Assessment

### *Performance statistics*

Model performance was assessed based on AUC values using a threshold of 0.7. Final ensembles were generated using AUC values.

### *Plausibility check*

I referred to the response curves of each algorithm to examine the plausibility of the most important explanatory variables.

### S2.1.5 Prediction

#### *Prediction output*

Prediction of probability of occurrence was expressed as 0.00 – 0.40 = low, 0.41 – 0.80 = moderate and 0.81 – 1.00 = high.

#### *Uncertainty quantification*

An ensemble approach was used combining all individual SDM algorithms that had performed well (≥0.7 AUC). The ensembles performed better than all single model algorithms and results from ensembles supported those of the individual algorithms and were able to overcome any discrepancies in most influential explanatory variable between single SDMs, although usually the single SDMs presented one of the top two variables presented by the ensemble.

## *S2.2: Preliminary ensemble species distribution modelling (years and benthic habitat within the Ningaloo Marine Park)*

### *S2.2.1 Collinearity testing*

Correlation testing revealed collinearity between water visibility and water depth in the years 2013, 2018 and 2019 (2013; $r = 0.73$, 2018; $r = 0.79$, 2019; $r = 0.74$). In 2018, a collinear relationship was also found between SST and water visibility ($r = 0.79$). Testing also revealed a VIF of >3 for water depth in all years of study except 2014 and 2015 (2013; VIF = 5.27, 2018; VIF = 5.11, 2019; VIF = 4.64). In 2014 and 2015, a VIF >3 was found for water visibility (2014; VIF = 3.52 and 2015; VIF = 10.60) and additionally in 2015, distance to boat ramp (VIF = 3.63).

Due to the ecological and biological importance of water depth reported in other coastal bottlenose dolphin habitat use studies (Heithaus and Dill, 2002, Heithaus and Dill, 2006, Sprogis et al., 2018a, Vargas-Fonesca et al., 2018, Zanardo et al., 2017, Passadore et al., 2018a), water visibility was dropped from the yearly SDMs as an explanatory variable. Additional correlation testing (after the removal of water visibility), revealed no further collinearity issues except for SST and distance to boast ramp in 2013 (r = 0.72) nor VIFs >3, except for distance to boat ramp in 2015. As these relationships were not replicated in any of the other models, they were treated as outliers and both SST and distance to boat ramp were retained in the set of potential explanatory variables.

### *S2.2.2 Results of yearly ensemble models of IP bottlenose dolphin distribution*

#### *S2.2.2.1 Model performance*

Most of the single yearly SDMs performed well (AUC > than 0.7), with the exception of several runs primarily from the ANN and GLM algorithms (AUC < 0.7) (Figure 8.1). All poor performing runs were excluded from the final ensemble models. Ensemble models outperformed all single SDMs with AUC values above 0.9 for all years indicating excellent model performance (2013; range = 0.46-0.82, median = 0.70, ensemble AUC = 0.96, 2014; range = 0.50 to 0.84, median = 0.76, ensemble AUC = 0.96, 2015: range = 0.44 to 0.81, median = 0.72, ensemble AUC = 0.98, 2018; range = 0.43 to 0.79, median = 0.63, ensemble AUC = 0.97 and 2019; range = 0.44 to 0.86, median = 0.73 and ensemble AUC = 0.96 (Figure 8.1).

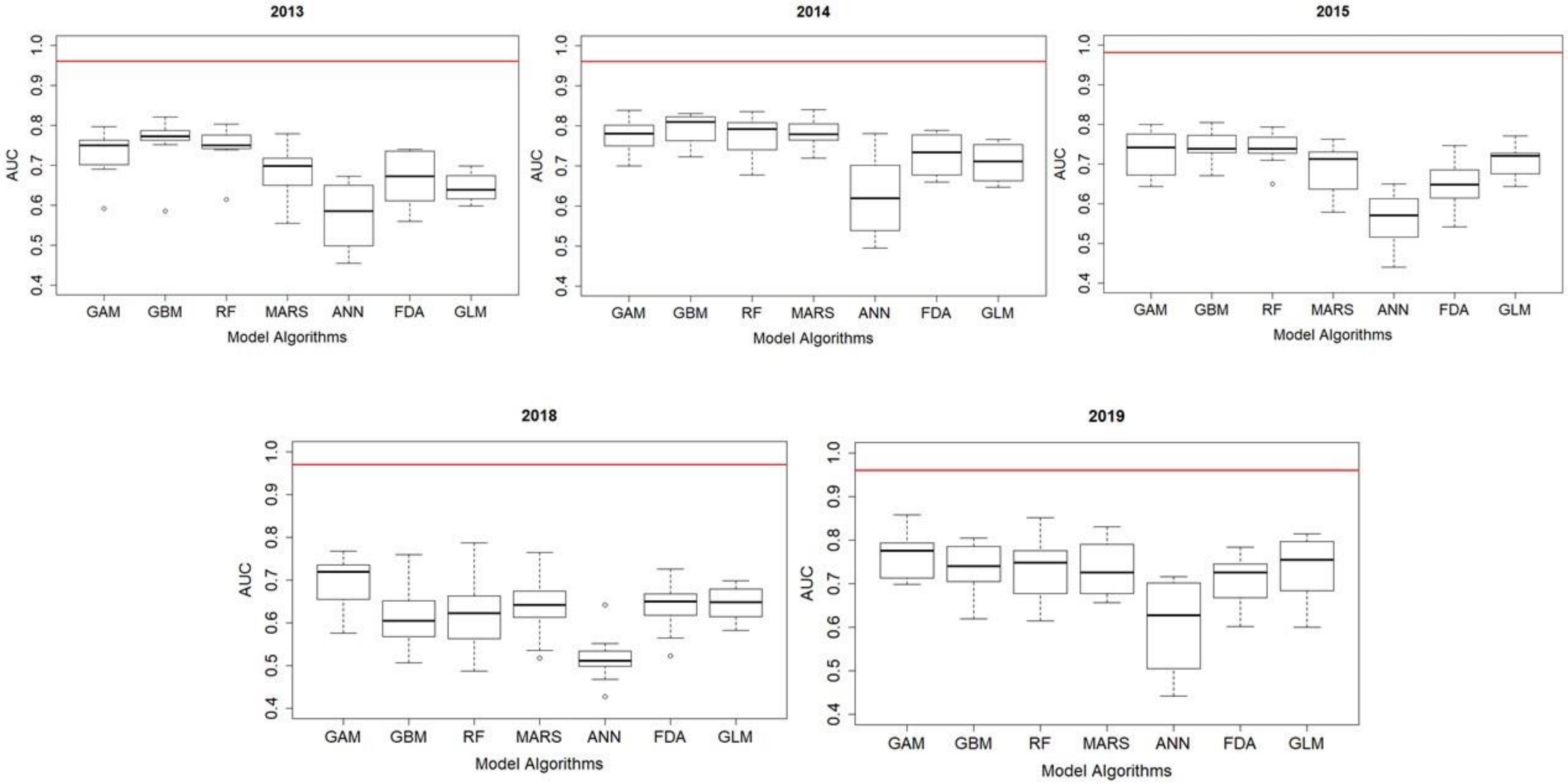


**Figure 8.1:** Performance of yearly species distribution models of Indo-Pacific bottlenose dolphins at the North West Cape, Western Australia. Boxplots for the AUC (area under the curve of the receiver-operating characteristic) of the 10-cross validation runs of each modelling algorithm (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model). The red line shows the AUC of the ensemble model for each year. Values of AUC ≥0.7 indicates that the model predictive performance is moderate to excellent.

### *S2.2.2.2 Variable importance and response curves*

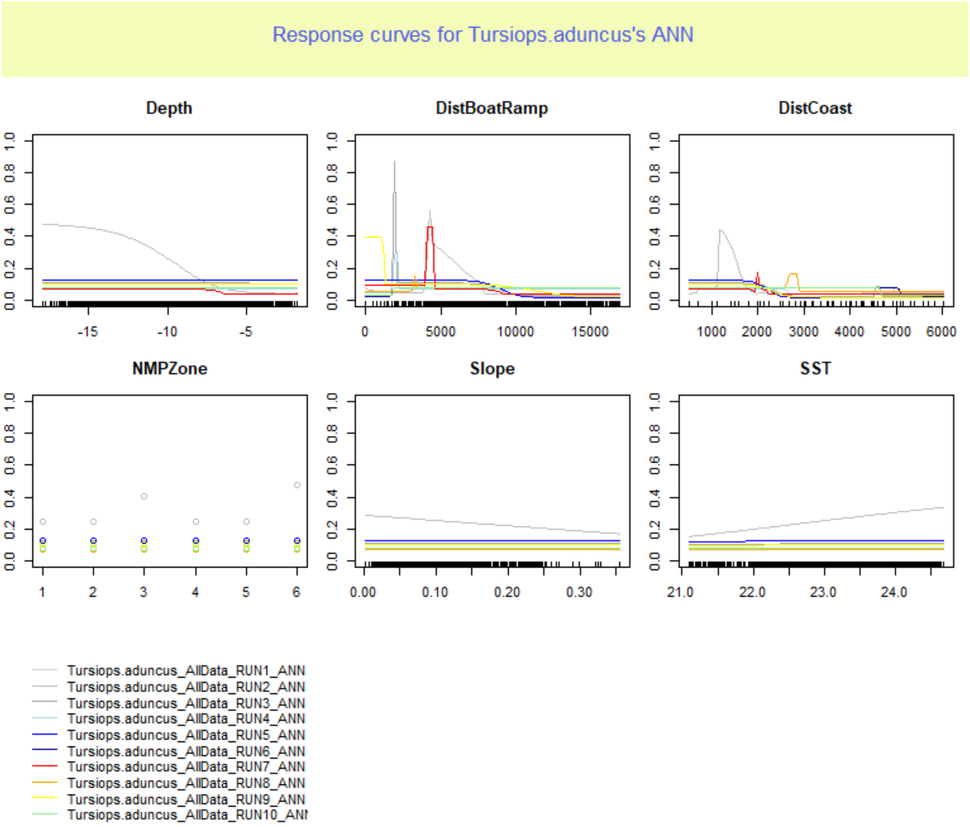
Most yearly SDMs, except for 2015, identified distance to coast as one of the most important variables influencing IP bottlenose dolphin distribution in the study area (Table 8.2). Response curves across these different yearly models indicated that the probability of IP bottlenose dolphin occurrence was highest up to 2000 m from the coast. Other important variables influencing dolphin occurrence varied by year and included water depth (2013), marine park zone (2014 and 2015); seabed slope (2015), SST (2018) and distance to boat ramp (2019). Response curves for these different variables indicated that the probability of dolphin occurrence also tended to be higher in : 1) water depths of 8 – 13 m in 2013, 2) in Sanctuary zones and Naval Waters in 2014; 3) in areas where the seabed slope was steeper in 2015, in water temperatures of ~ 22 – 23.5°C in 2018; and in waters up to 10 000 m from the nearest boat ramp in 2019 (see sections S2.2.2.2.1 – S2.2.2.2.5 of this Appendix)

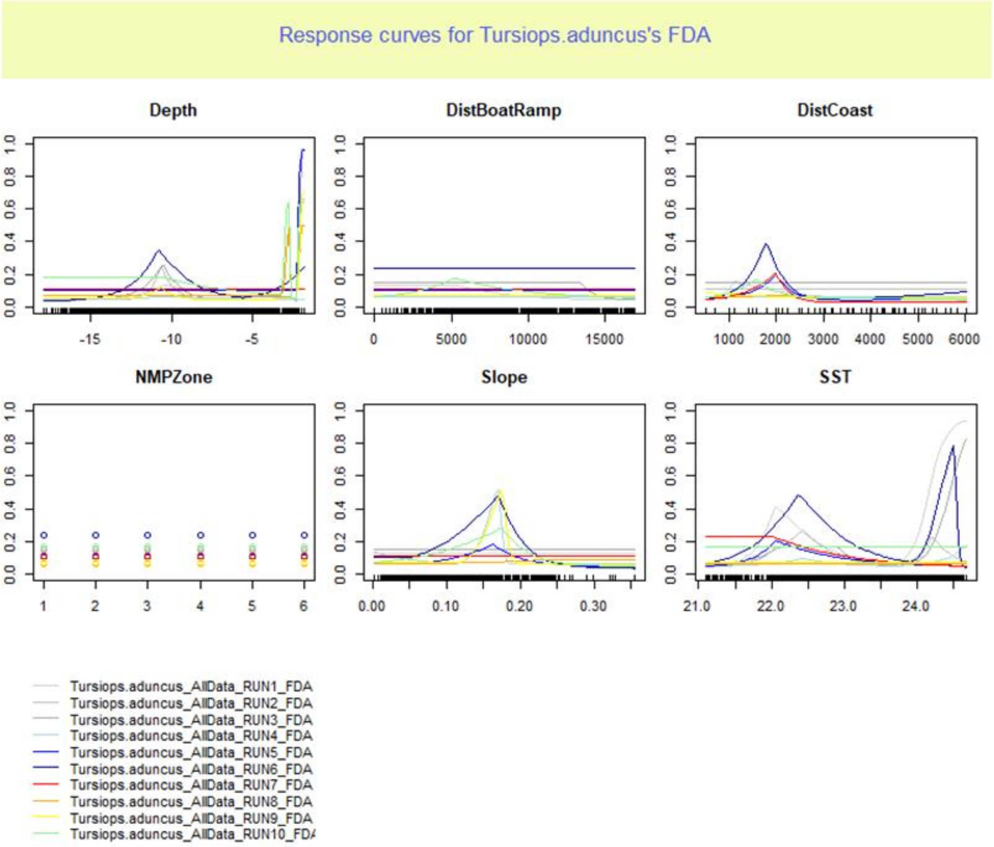
**Table 8.2:** Importance of predictor variables used in the yearly species distribution models (SDMs) of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) at the North West Cape, Western Australia. Eight SDM algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), maximum entropy (MaxEnt), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as the ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

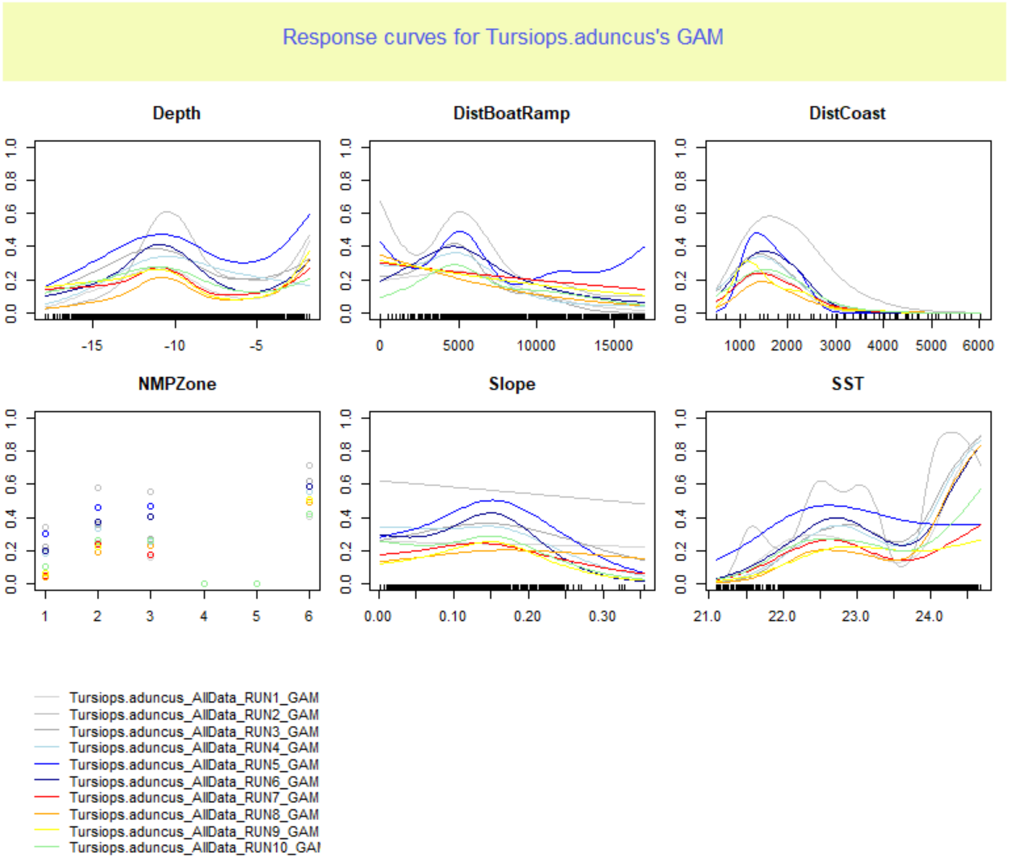
| **Year** | **Model** | **Explanatory variables** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** |
| 2013 | ANN$^{0}$ | **0.80** | **0.80** | 0.04 | 0.00 | 0.02 | 0.06 |
| | FDA$^{3}$ | 0.03 | 0.20 | 0.00 | 0.17 | 0.26 | **0.64** |
| | GAM$^{8}$ | 0.26 | **0.57** | 0.26 | 0.04 | 0.33 | 0.19 |
| | GBM$^{9}$ | 0.11 | **0.40** | 0.01 | 0.33 | 0.25 | 0.12 |
| | GLM$^{0}$ | 0.19 | **0.59** | 0.17 | 0.08 | 0.00 | 0.02 |
| | MARS$^{5}$ | 0.14 | **0.52** | 0.00 | 0.10 | 0.26 | 0.40 |
| | RF$^{9}$ | 0.16 | **0.27** | 0.03 | 0.26 | 0.24 | 0.14 |
| | Mean of means | 0.24 | **0.48** | 0.07 | 0.14 | 0.19 | **0.22** |
| | Ensemble | 0.16 | **0.42** | 0.07 | 0.18 | **0.30** | 0.25 |
| 2014 | ANN$^{3}$ | 0.83 | **0.86** | 0.09 | 0.00 | 0.01 | 0.14 |
| | FDA$^{6}$ | 0.04 | 0.32 | 0.40 | 0.23 | **0.49** | 0.06 |
| | GAM$^{10}$ | 0.04 | 0.36 | **0.44** | 0.25 | 0.21 | 0.05 |
| | GBM$^{10}$ | 0.09 | **0.39** | 0.17 | 0.15 | 0.37 | 0.08 |
| | GLM$^{6}$ | 0.02 | 0.03 | **0.71** | 0.02 | 0.32 | 0.03 |
| | MARS$^{10}$ | 0.00 | **0.52** | 0.26 | 0.28 | 0.25 | 0.05 |
| | RF$^{9}$ | 0.15 | **0.27** | 0.13 | 0.13 | **0.27** | 0.13 |
| | Mean of means | 0.17 | **0.40** | **0.31** | 0.15 | 0.27 | 0.17 |
| | Ensemble | 0.14 | **0.39** | **0.36** | 0.14 | 0.27 | 0.06 |
| 2015 | ANN$^{0}$ | **0.85** | 0.80 | 0.07 | 0.00 | 0.01 | 0.12 |

| Year | Model | Explanatory variables | | | | | |
|---|---|---|---|---|---|---|---|
| | | Distance to boat ramp | Distance to coast | MP zone | Seabed slope | SST | Water depth |
| | FDA$^{2}$ | 0.05 | 0.09 | **0.63** | 0.31 | 0.13 | 0.06 |
| | GAM$^{6}$ | 0.17 | 0.26 | **0.39** | 0.34 | 0.29 | 0.18 |
| | GBM$^{8}$ | 0.20 | 0.12 | 0.12 | **0.53** | 0.43 | 0.15 |
| | GLM$^{7}$ | 0.06 | 0.08 | **0.48** | 0.43 | 0.35 | 0.06 |
| | MARS$^{6}$ | 0.09 | 0.37 | 0.12 | **0.38** | 0.22 | 0.22 |
| | RF$^{9}$ | 0.22 | 0.11 | 0.11 | **0.36** | 0.33 | 0.13 |
| | Mean of means | 0.24 | 0.26 | **0.27** | **0.34** | 0.25 | 0.13 |
| | Ensemble | 0.10 | 0.19 | **0.36** | **0.31** | 0.27 | 0.13 |
| 2018 | ANN$^{0}$ | **0.81** | 0.80 | 0.00 | 0.00 | 0.02 | 0.07 |
| | FDA$^{1}$ | 0.02 | 0.26 | 0.12 | 0.15 | **0.55** | 0.34 |
| | GAM$^{6}$ | 0.08 | 0.42 | 0.36 | 0.08 | **0.43** | 0.12 |
| | GBM$^{2}$ | 0.11 | 0.09 | 0.10 | 0.38 | **0.58** | 0.17 |
| | GLM$^{0}$ | 0.00 | 0.08 | 0.10 | 0.17 | **0.70** | 0.10 |
| | MARS$^{2}$ | 0.07 | 0.43 | 0.03 | 0.13 | **0.52** | 0.22 |
| | RF$^{2}$ | 0.12 | 0.11 | 0.06 | 0.24 | **0.36** | 0.16 |
| | Mean of means | 0.17 | **0.31** | 0.11 | 0.16 | **0.45** | 0.17 |
| | Ensemble | 0.10 | **0.18** | 0.10 | 0.16 | **0.60** | 0.06 |
| 2019 | ANN$^{4}$ | **0.85** | 0.80 | 0.09 | 0.08 | 0.03 | 0.37 |
| | FDA$^{6}$ | 0.25 | 0.22 | 0.00 | **0.44** | 0.41 | 0.07 |
| | GAM$^{9}$ | **0.52** | **0.52** | 0.26 | 0.17 | 0.06 | 0.20 |
| | GBM$^{8}$ | 0.32 | 0.23 | 0.01 | **0.47** | 0.28 | 0.10 |
| | GLM$^{7}$ | **0.46** | 0.34 | 0.00 | 0.38 | 0.06 | 0.00 |
| | MARS$^{6}$ | 0.35 | **0.47** | 0.00 | 0.31 | 0.12 | 0.07 |
| | RF$^{6}$ | 0.28 | 0.19 | 0.04 | **0.31** | 0.23 | 0.12 |
| | Mean of means | **0.43** | **0.40** | 0.06 | 0.31 | 0.17 | 0.13 |
| | Ensemble | **0.42** | **0.39** | 0.06 | 0.30 | 0.19 | 0.13 |

### *S2.2.2.2.1 2013 Response curves*






Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.00
0.10
0.20
0.30
21.0
22.0
23.0
24.0
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
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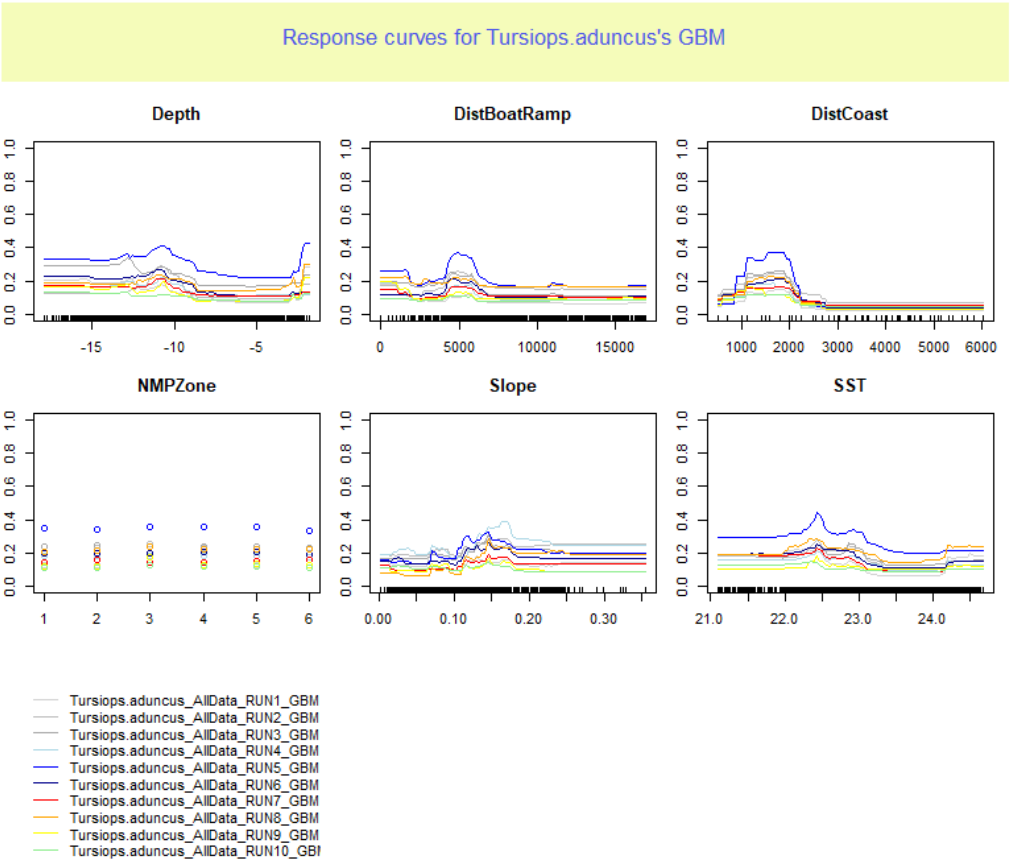
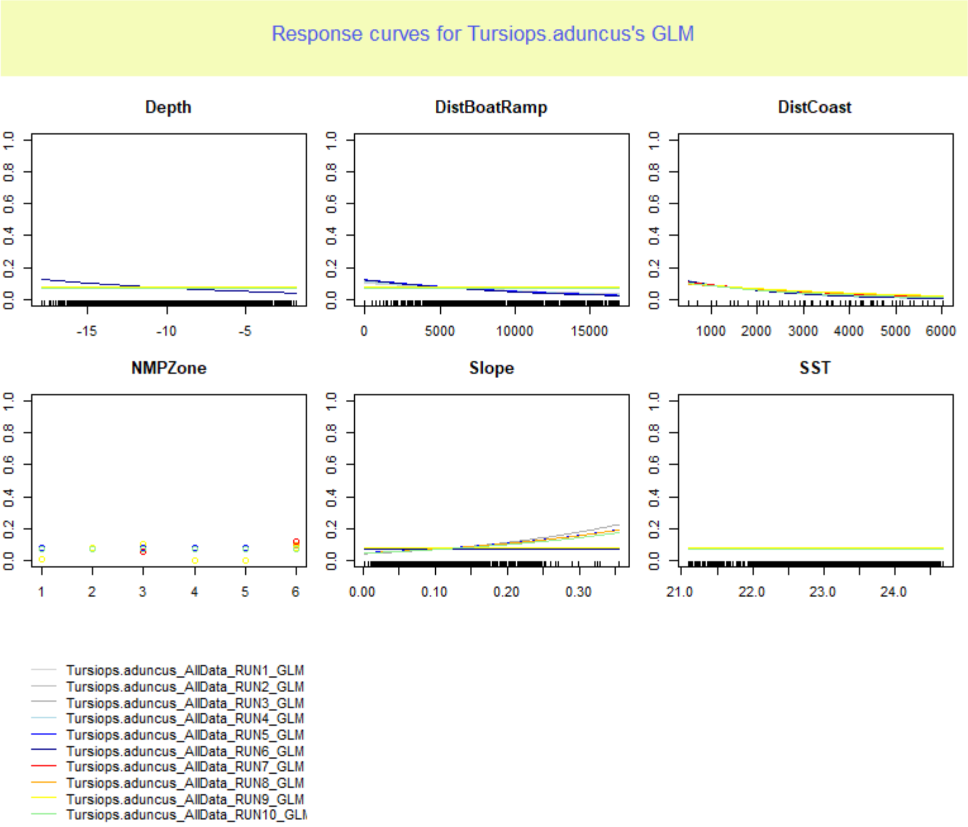
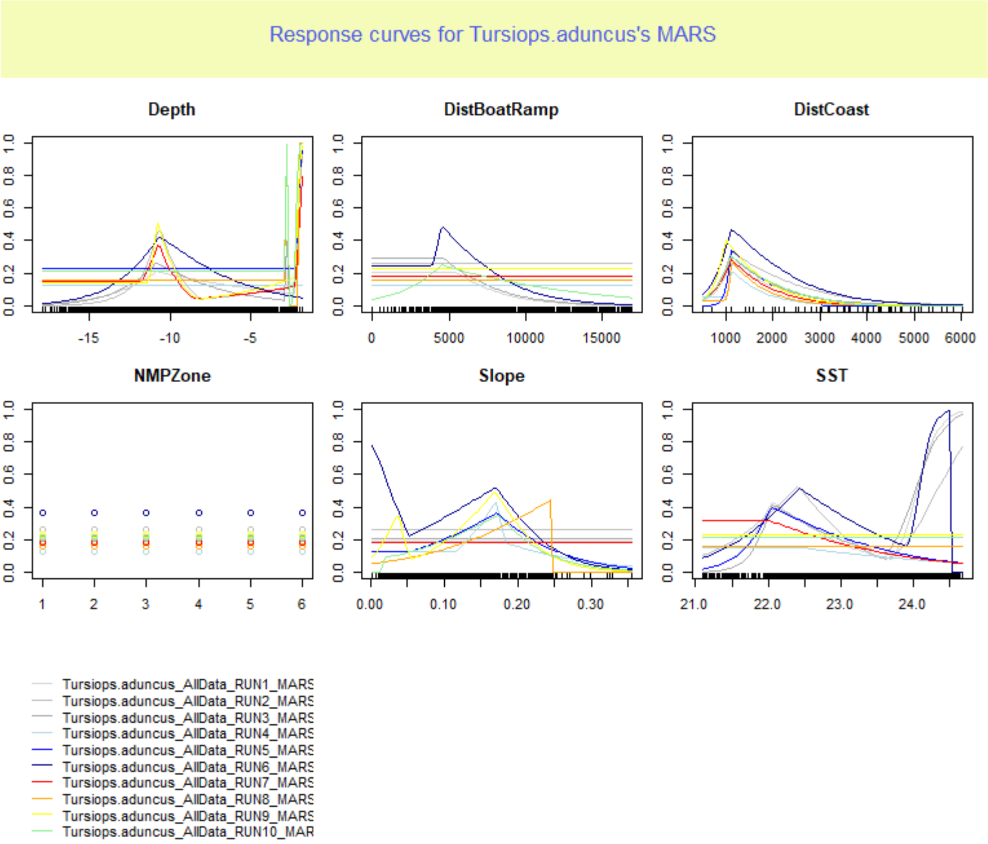
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GAI


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.00
0.10
0.20
0.30
21.0
22.0
23.0
24.0
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
Tursiops.aduncus_AllData_RUN9_GBM
Tursiops.aduncus_AllData_RUN10_GBI


Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.00 0.10 0.20 0.30
21.0 22.0 23.0 24.0
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
Tursiops.aduncus_AllData_RUN8_GLM
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GLI


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
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-15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.00 0.10 0.20 0.30
21.0 22.0 23.0 24.0
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

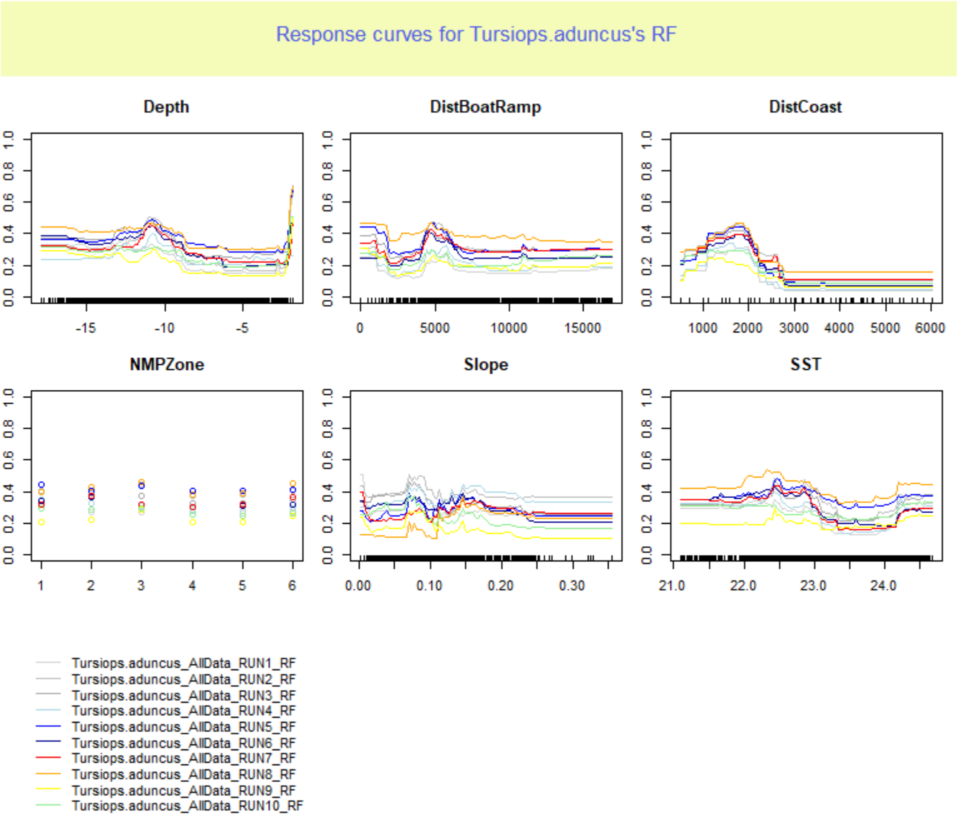
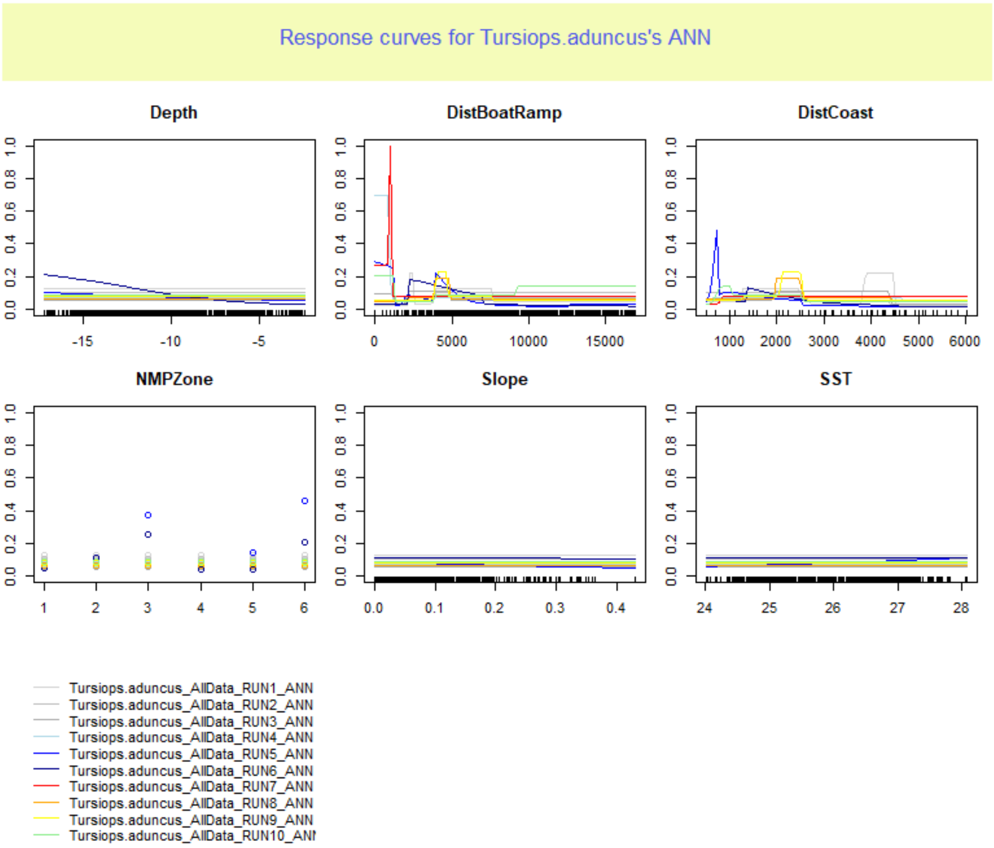
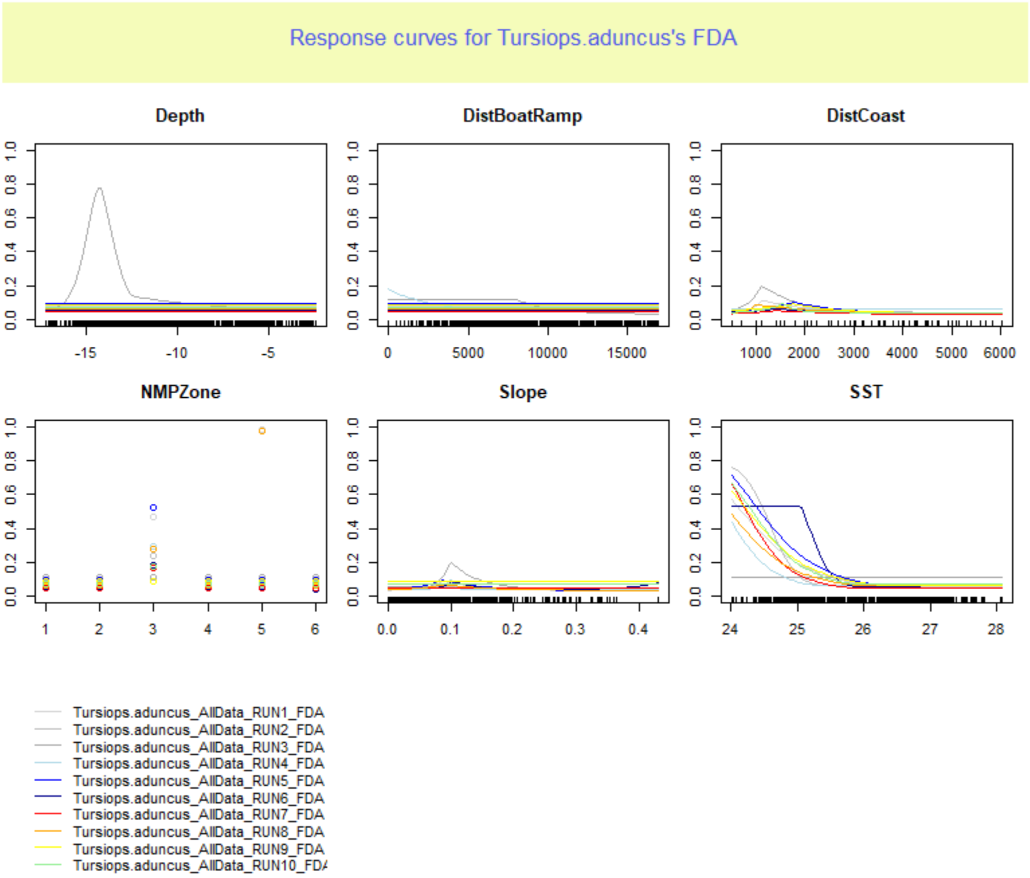
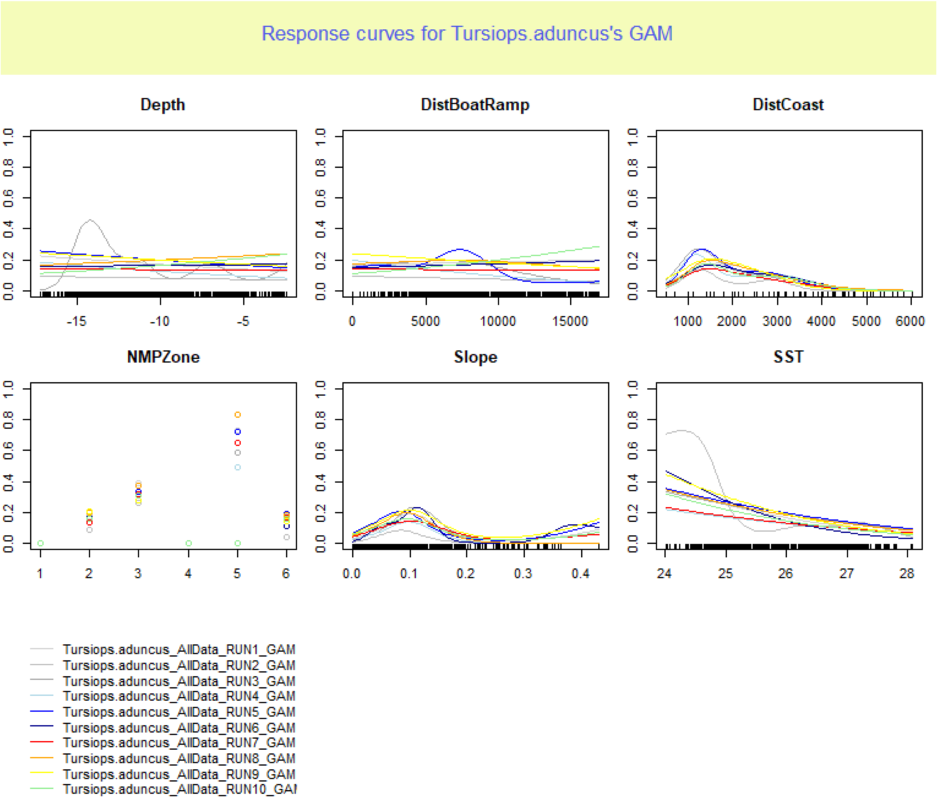


**Figure 8.2:** Response curves of the seven modelling algorithms used in the ensemble to model 2013 Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

### *S2.2.2.2.2 2014 Response curves*






Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.1
0.2
0.3
0.4
24
25
26
27
28
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
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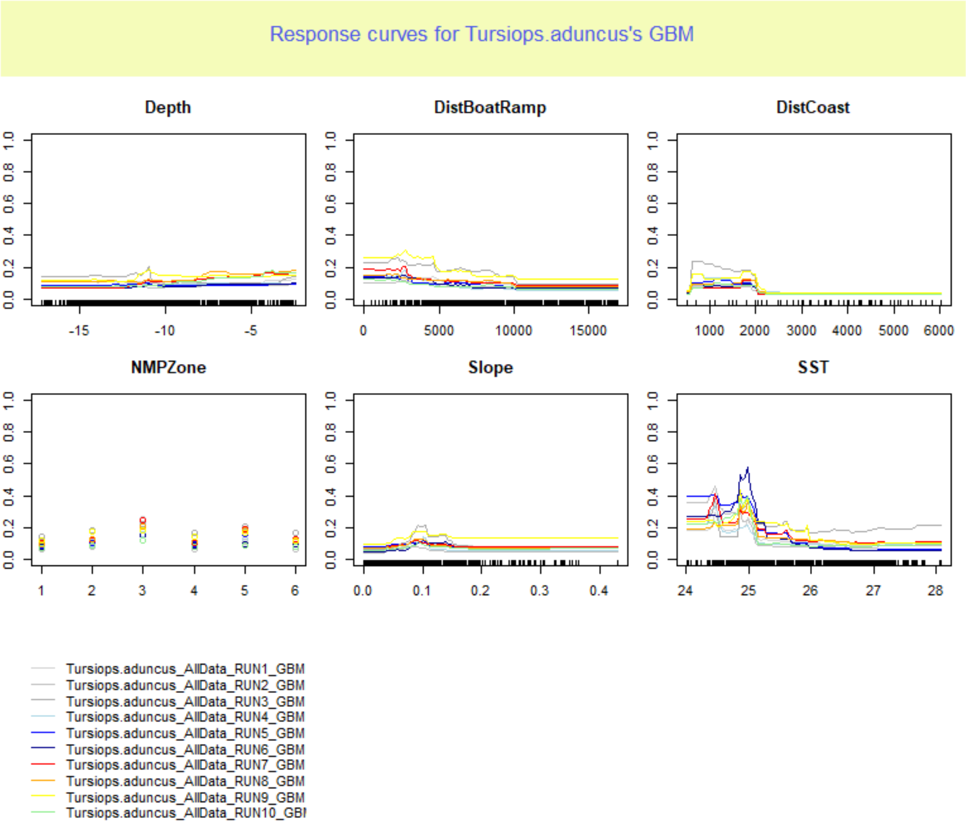
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GAI


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
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0.2
0.4
0.6
0.8
1.0
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.1
0.2
0.3
0.4
24
25
26
27
28
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
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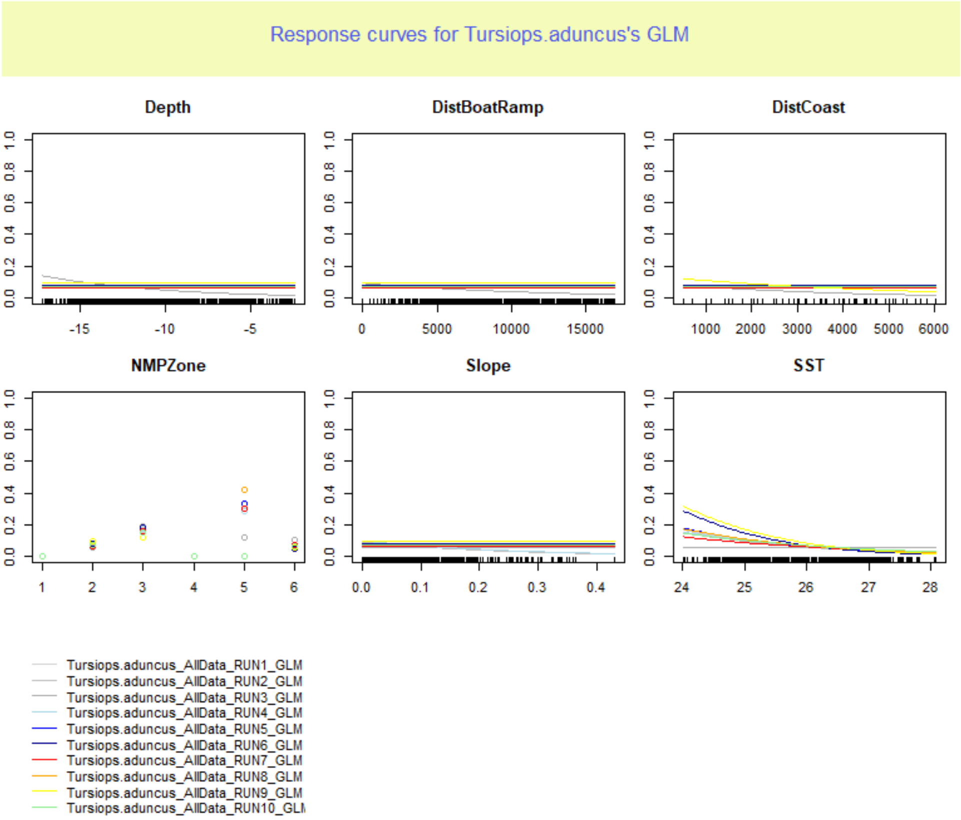
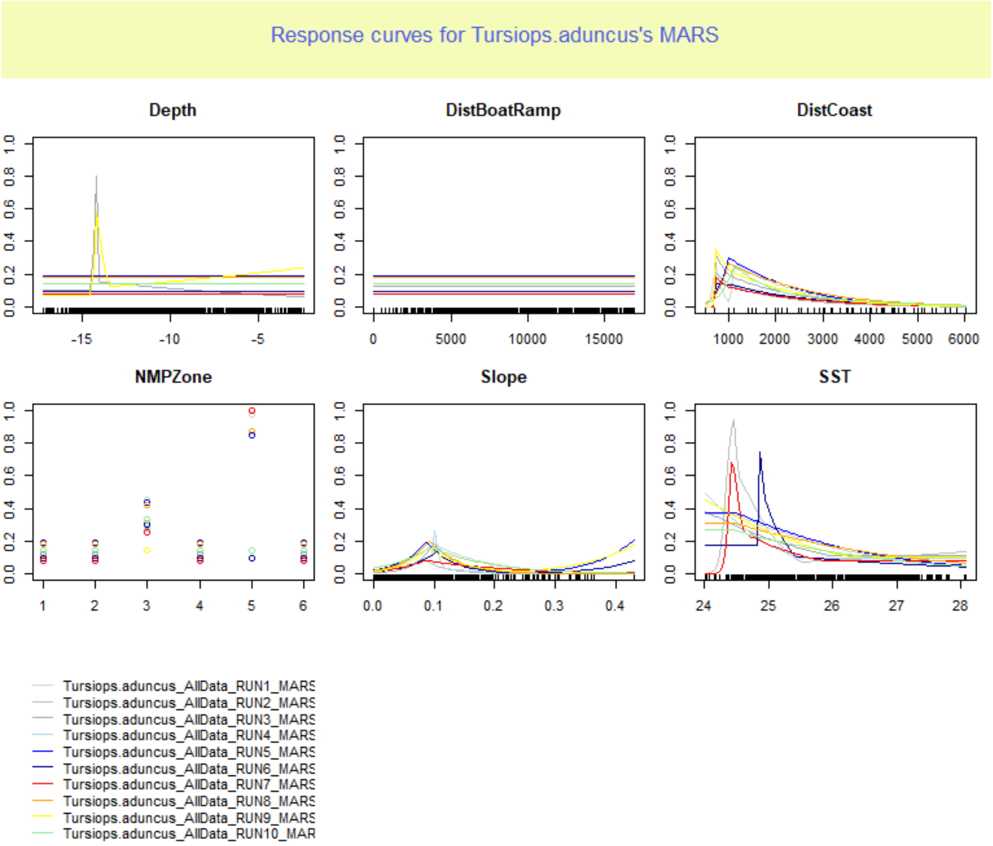
Tursiops.aduncus_AllData_RUN10_GBI


Response curves for Tursiops.aduncus's GLM


Response curves for Tursiops.aduncus's MARS

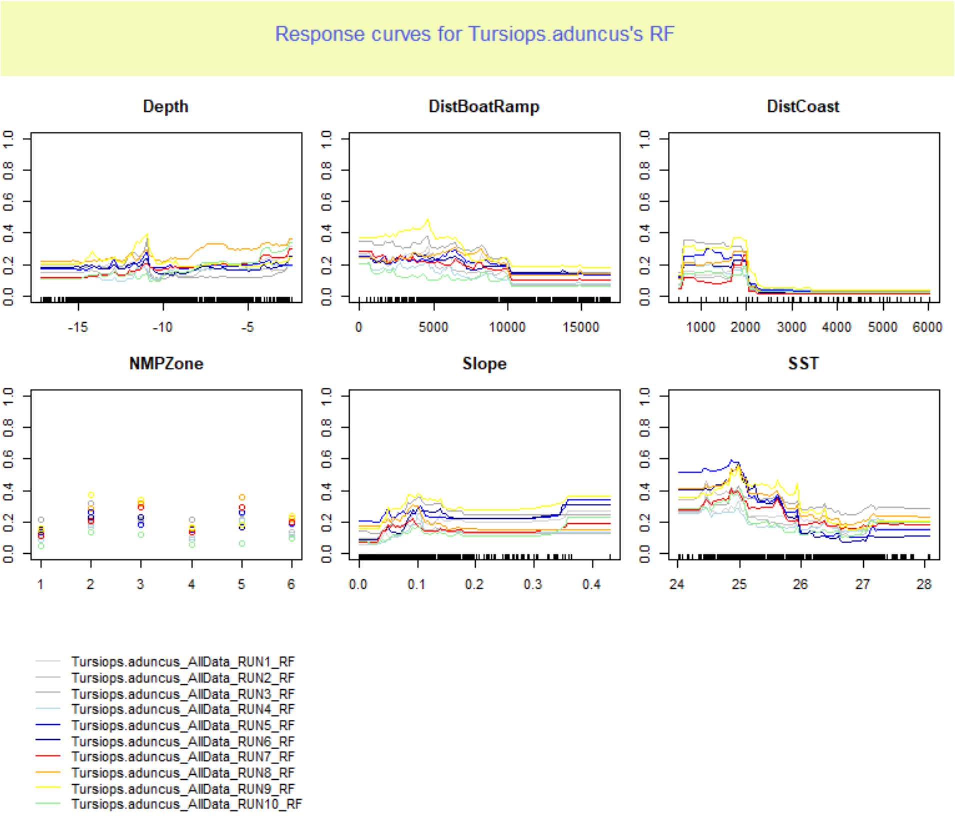
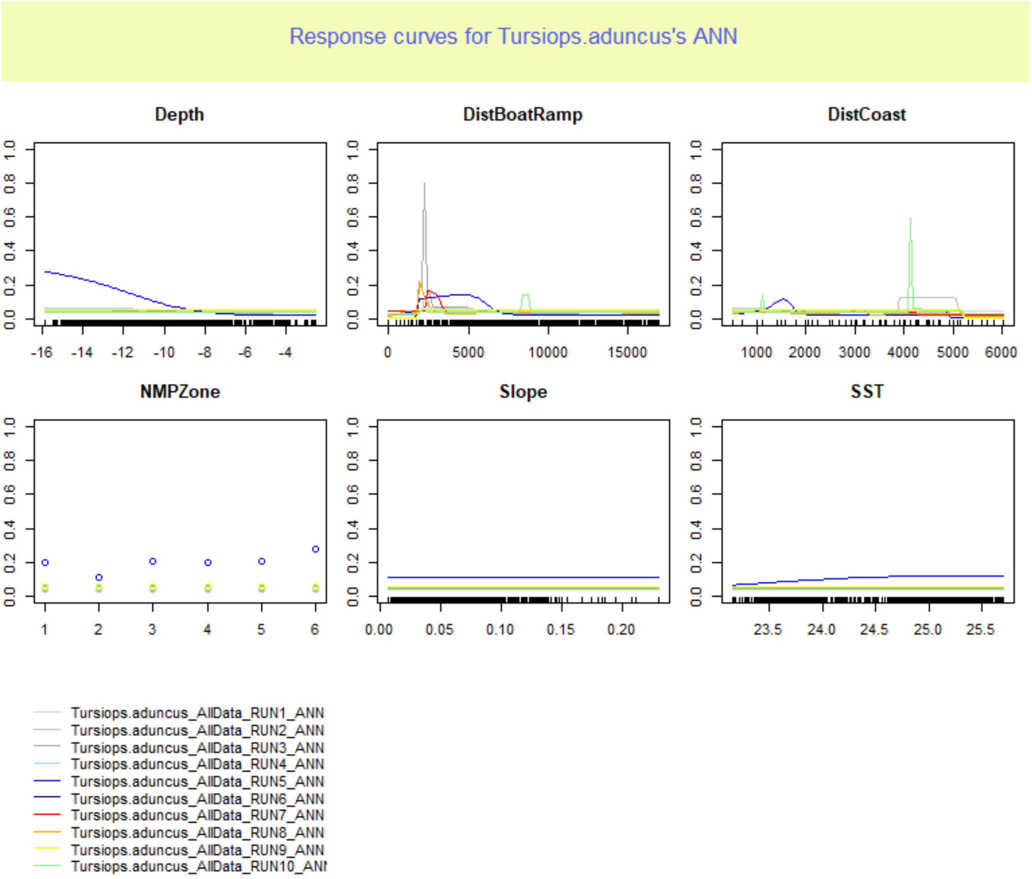
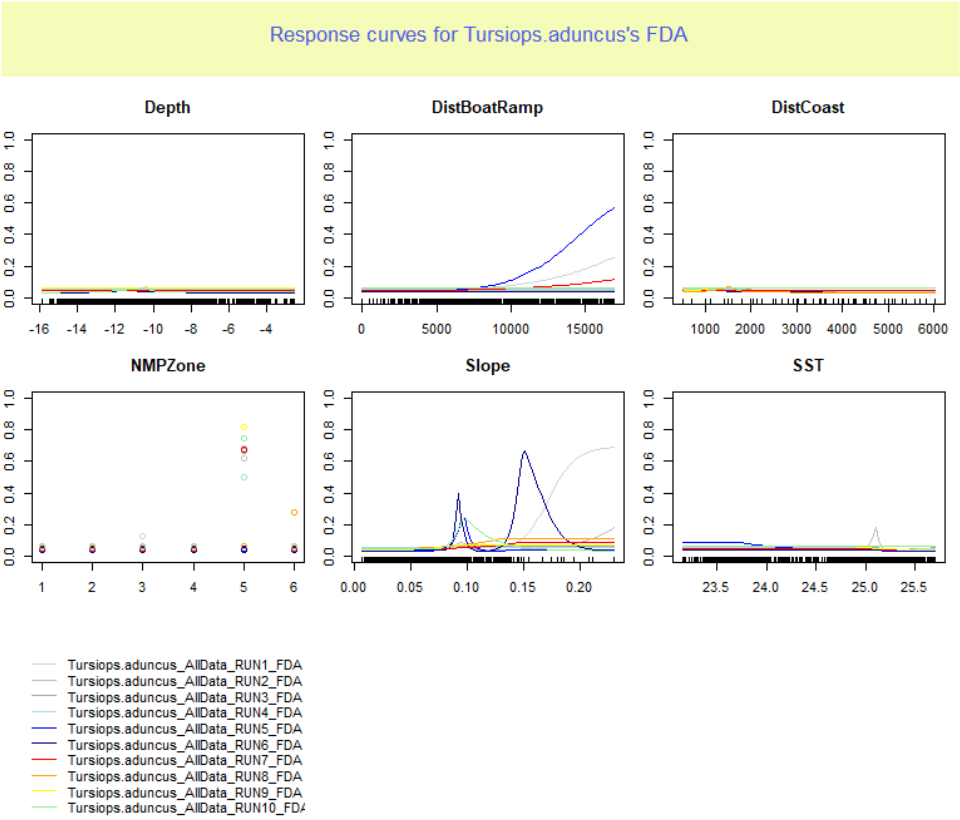


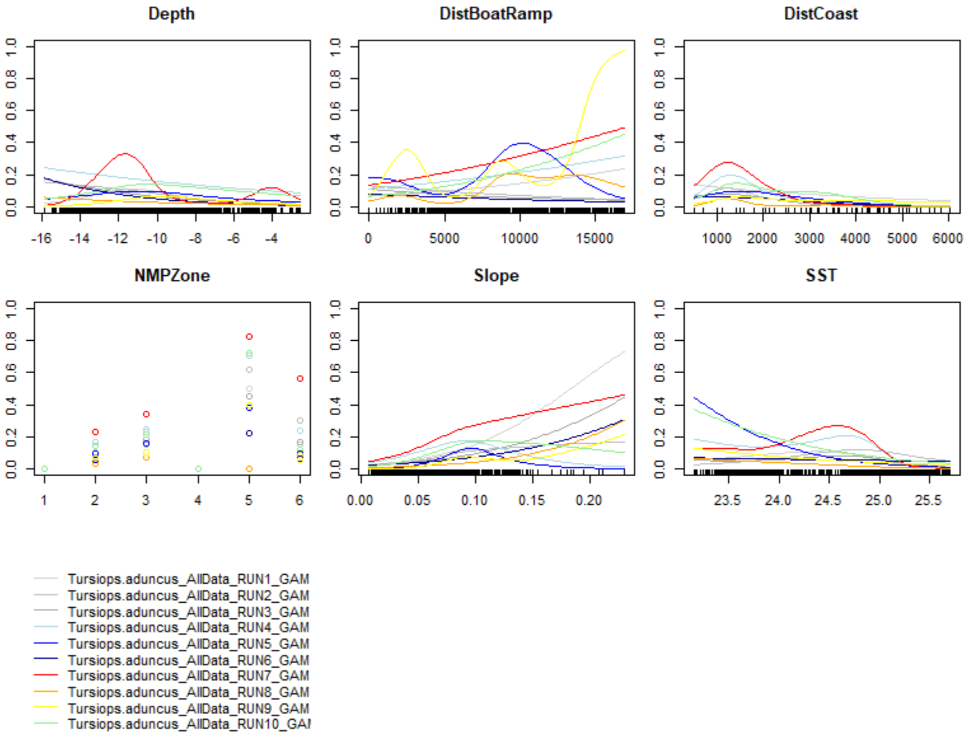
**Figure 8.3:** Response curves of the seven modelling algorithms used in the ensemble to model 2014 Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

### *S2.2.2.2.3 2015 Response curves*

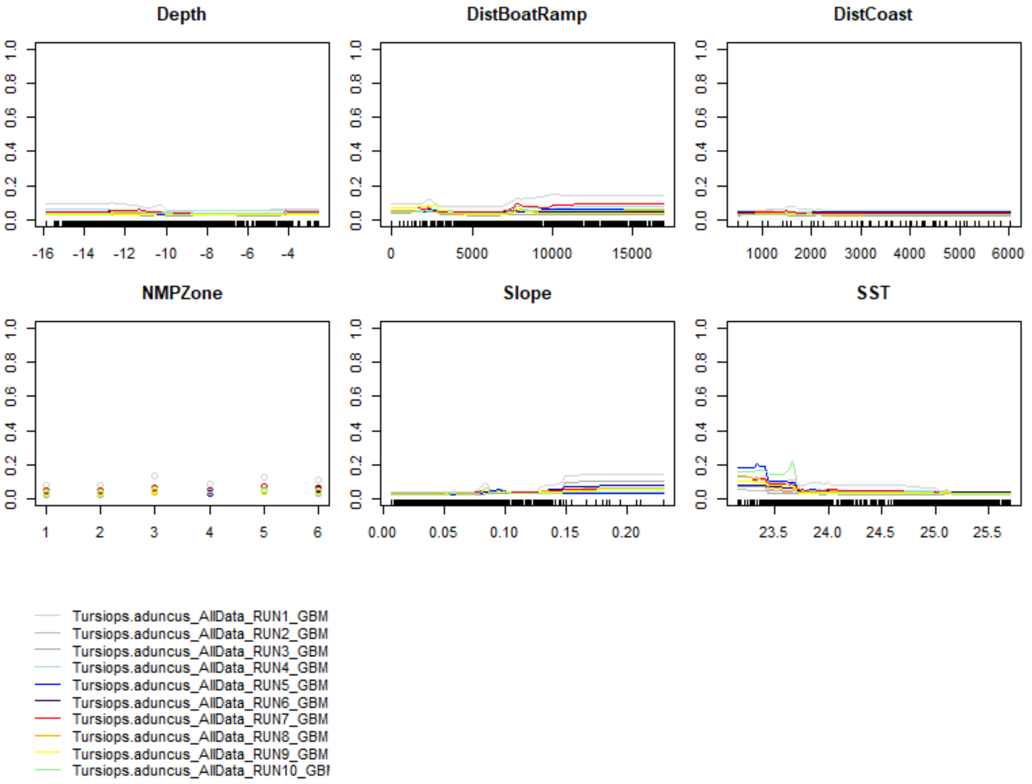


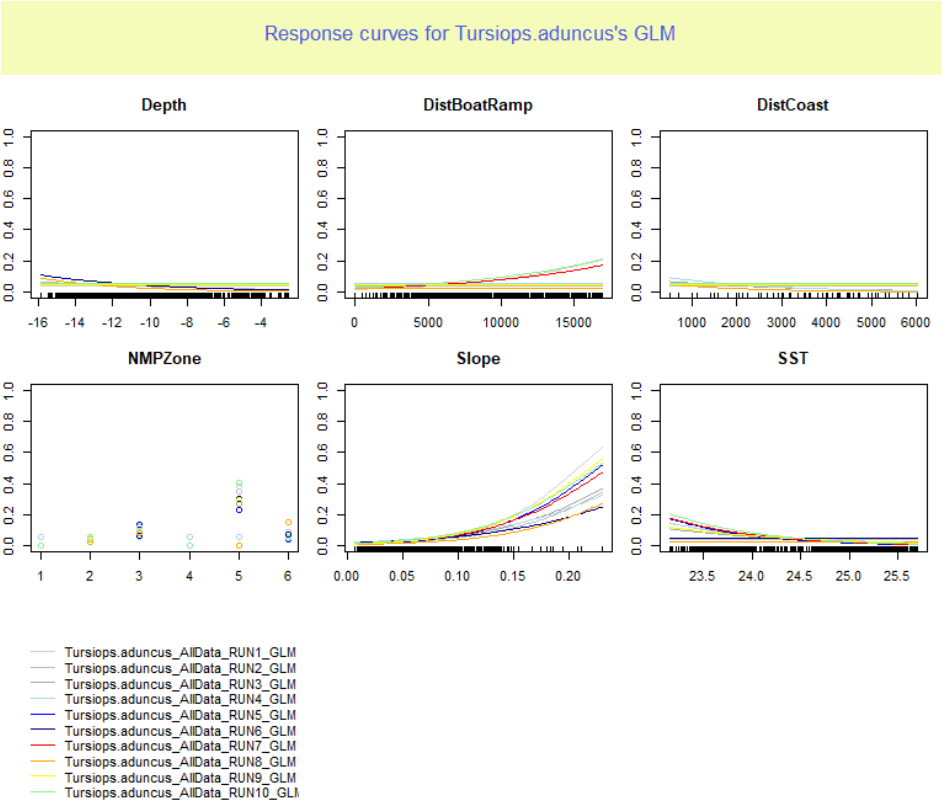


Response curves for Tursiops.aduncus's GAM



Response curves for Tursiops.aduncus's GBM




Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-16 -14 -12 -10 -8 -6 -4
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.00 0.05 0.10 0.15 0.20
23.5 24.0 24.5 25.0 25.5
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
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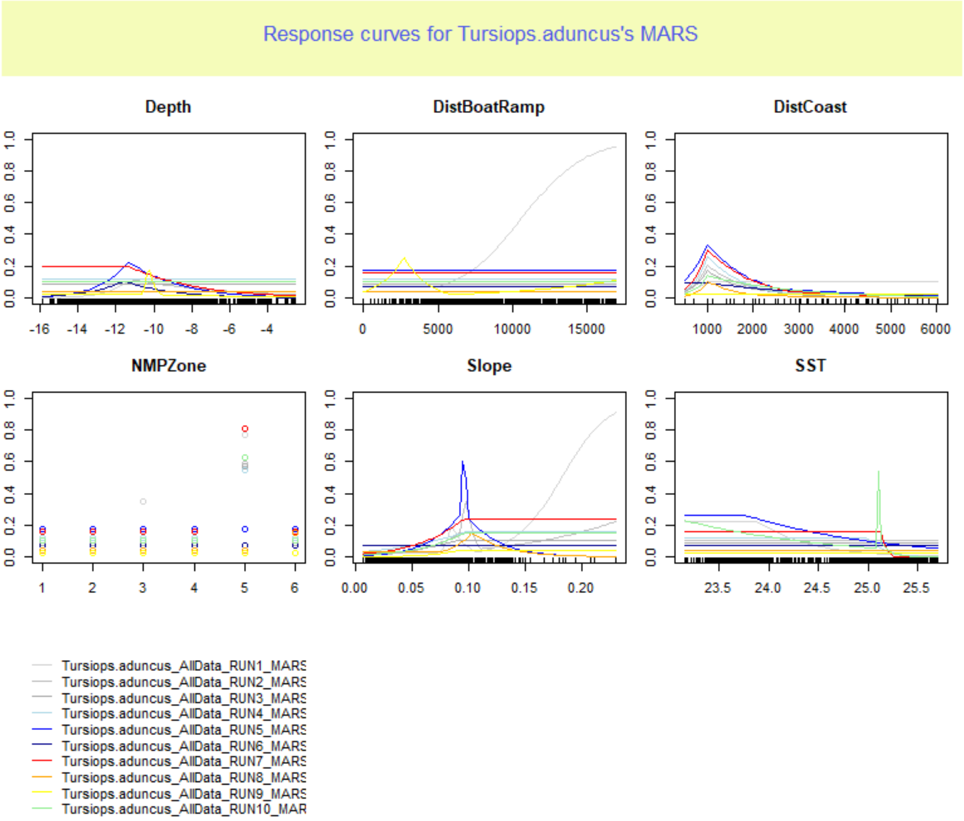
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-16 -14 -12 -10 -8 -6 -4
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.00 0.05 0.10 0.15 0.20
23.5 24.0 24.5 25.0 25.5
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
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Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

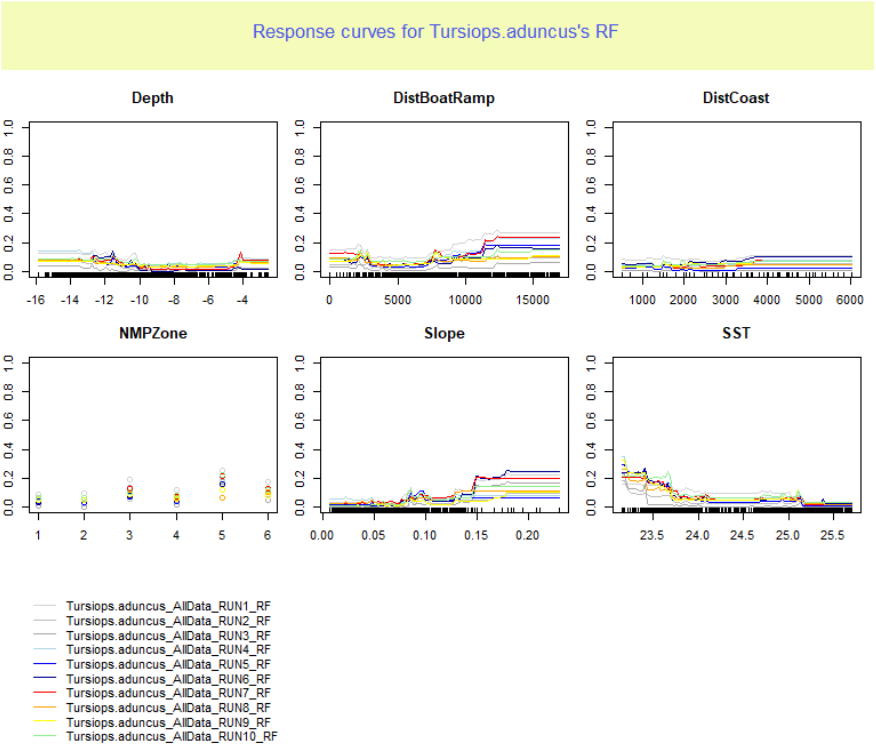
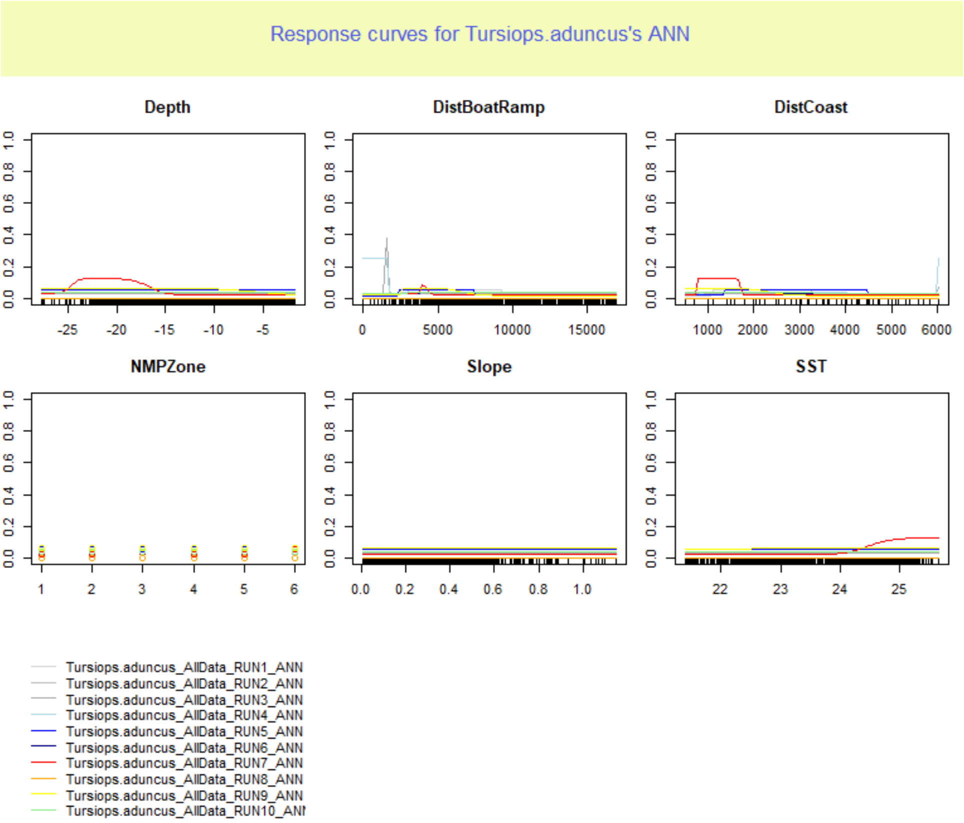
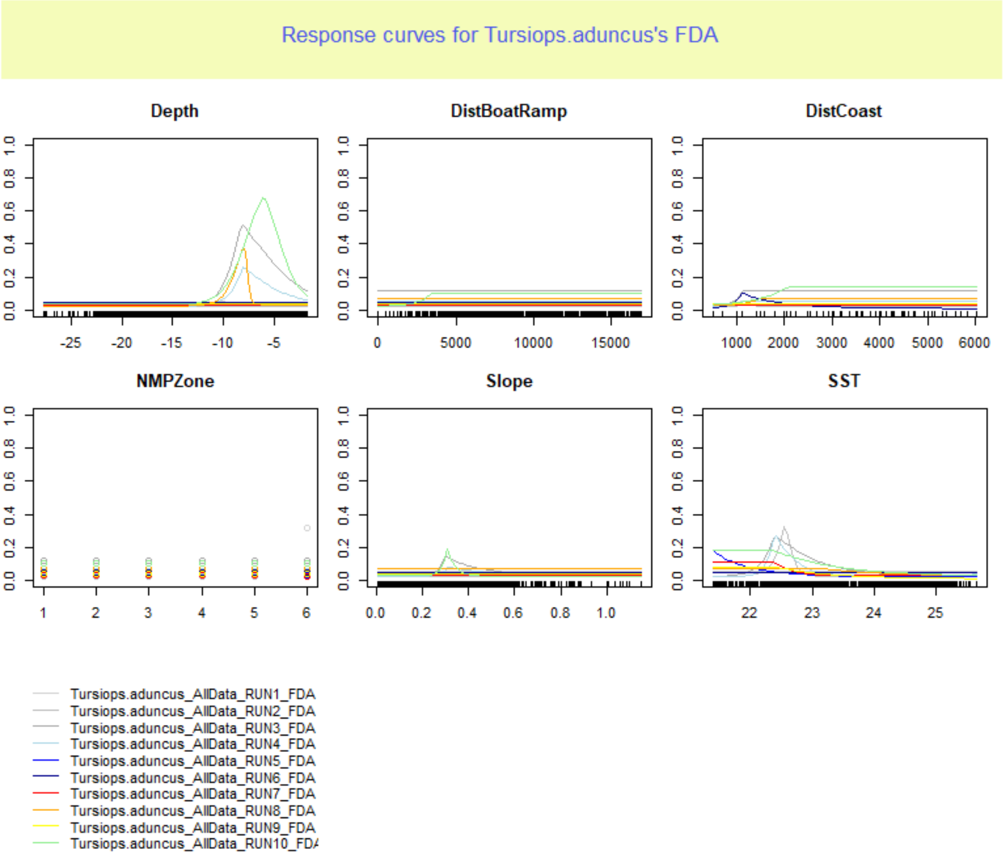


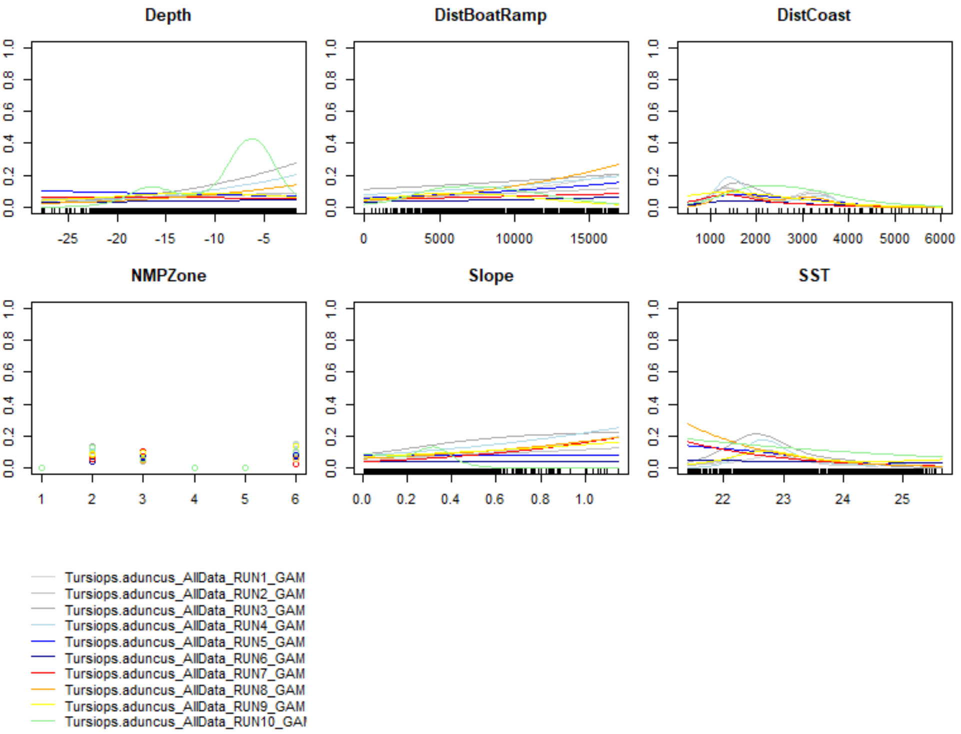
**Figure 8.4:** Response curves of the seven modelling algorithms used in the ensemble to model 2015 Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

## *S2.2.2.2.4 2018 Response curves*

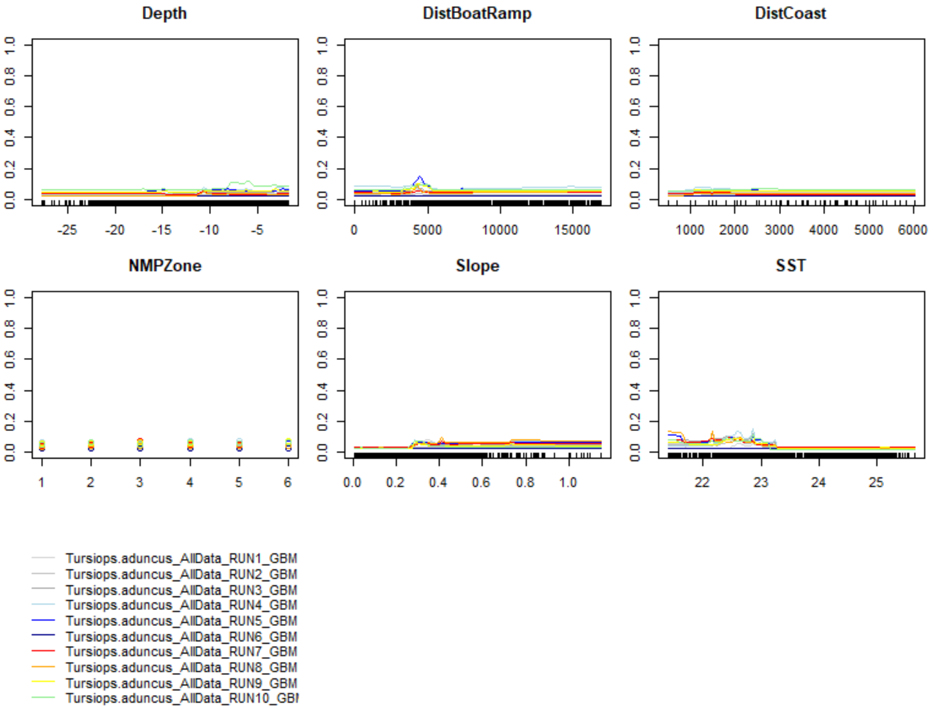


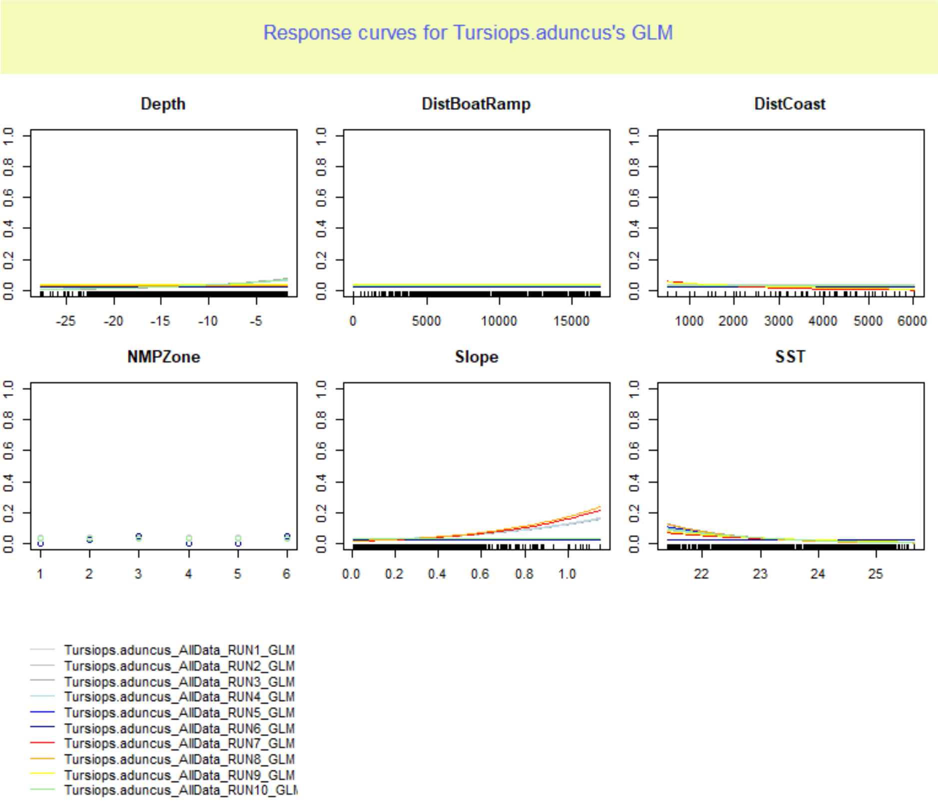


Response curves for Tursiops.aduncus's GAM



Response curves for Tursiops.aduncus's GBM




Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
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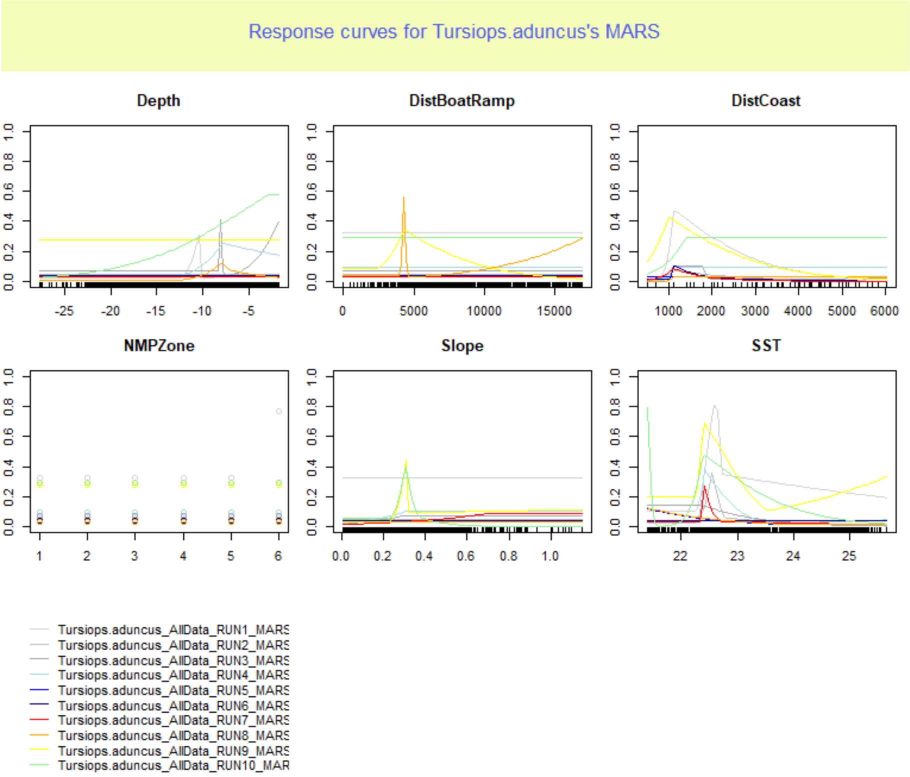
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

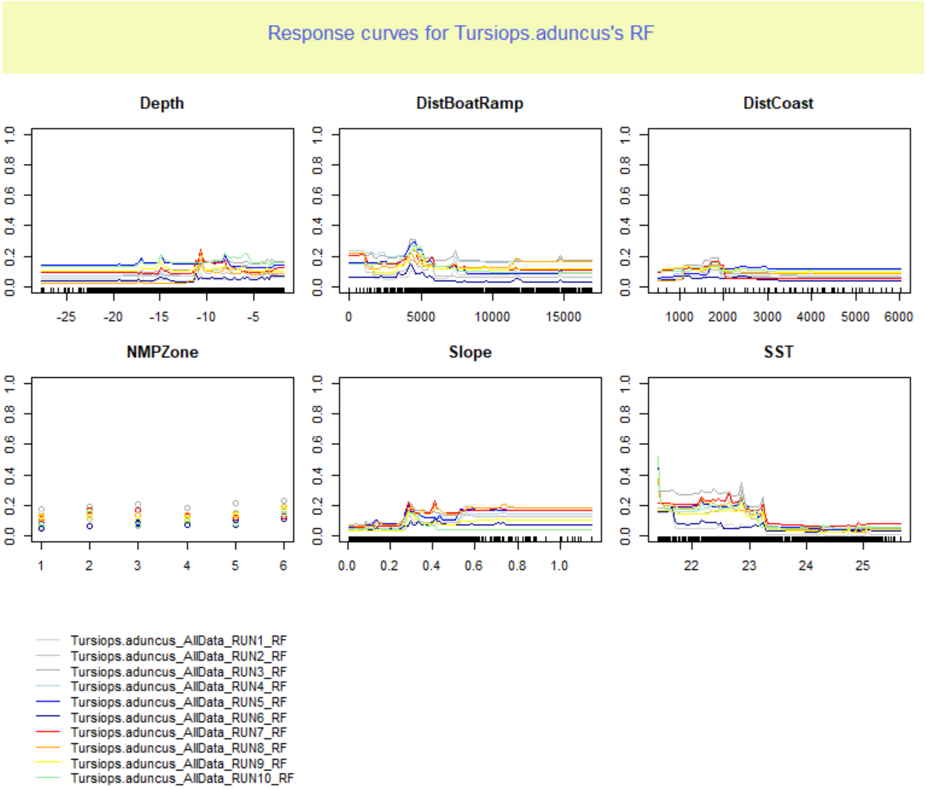
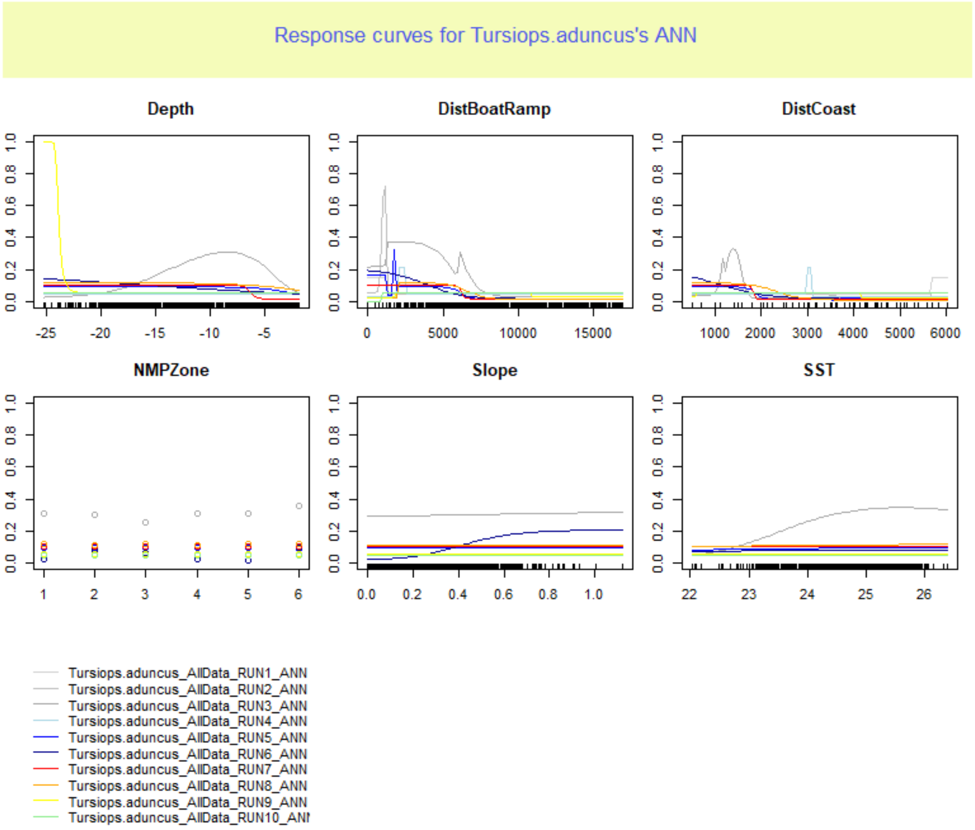
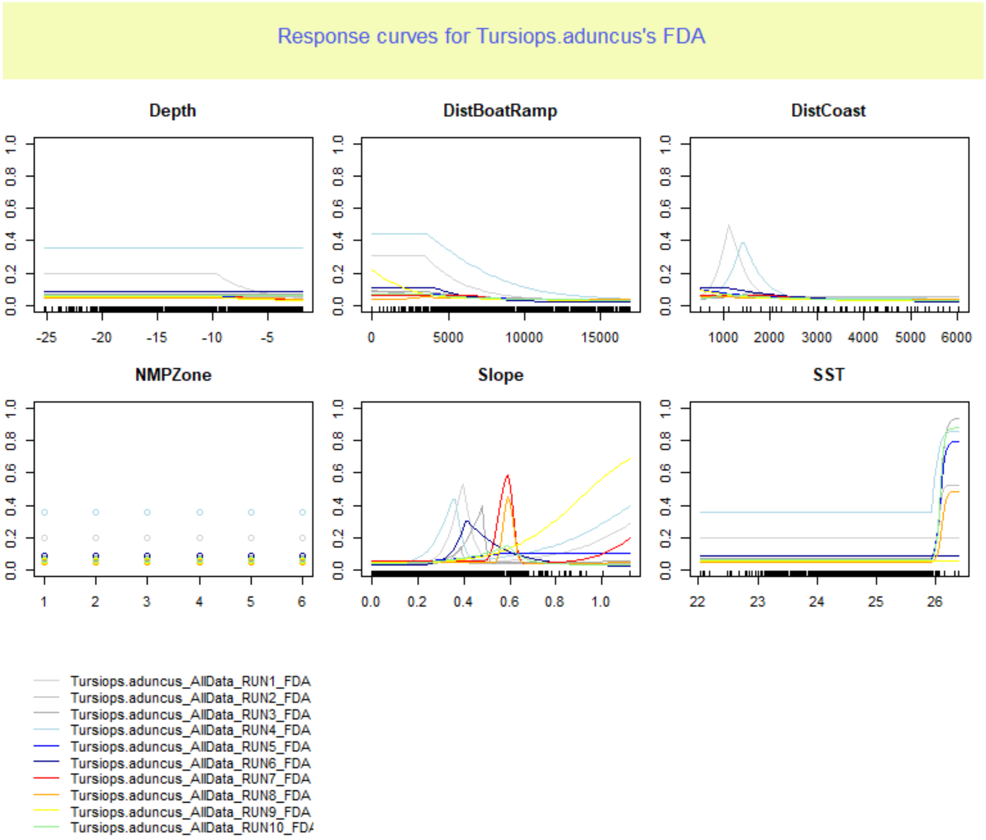
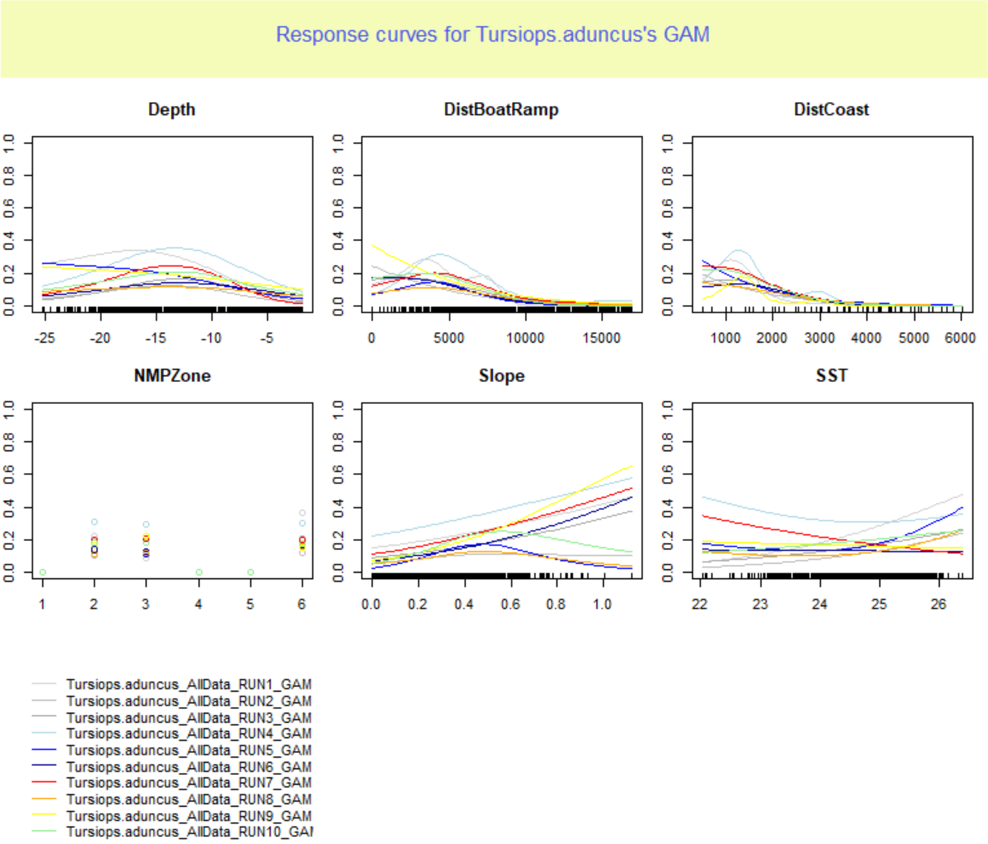


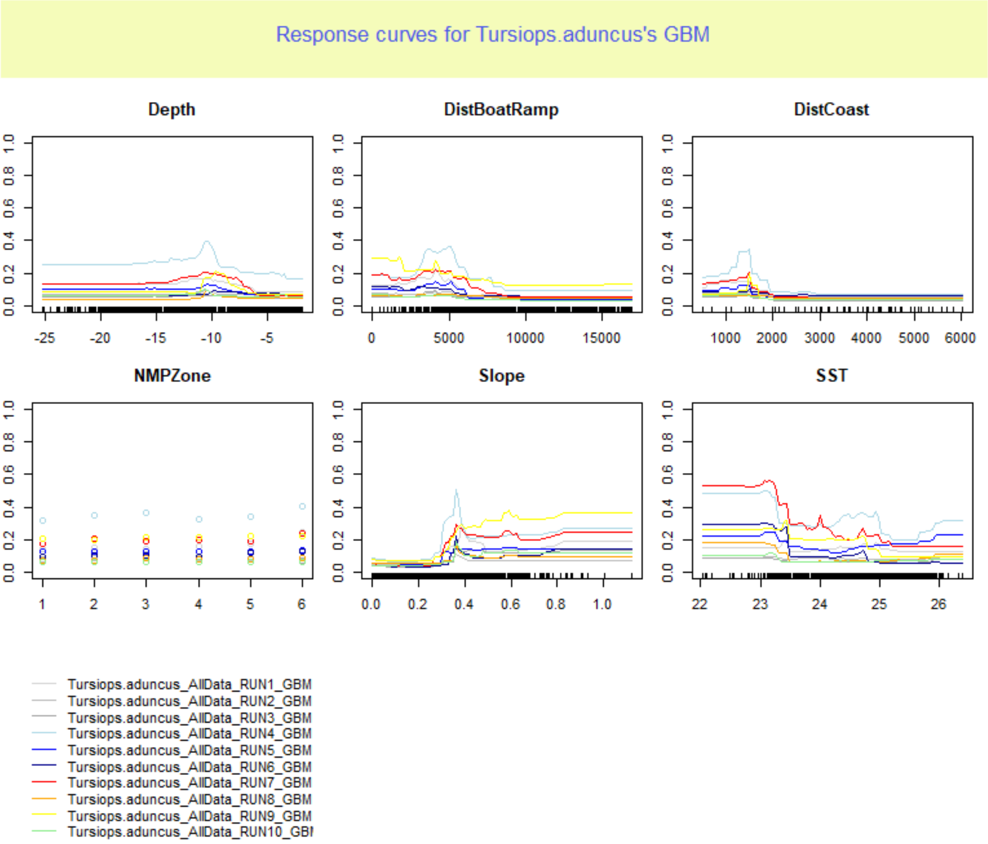
**Figure 8.5:** Response curves of the seven modelling algorithms used in the ensemble to model 2018 Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

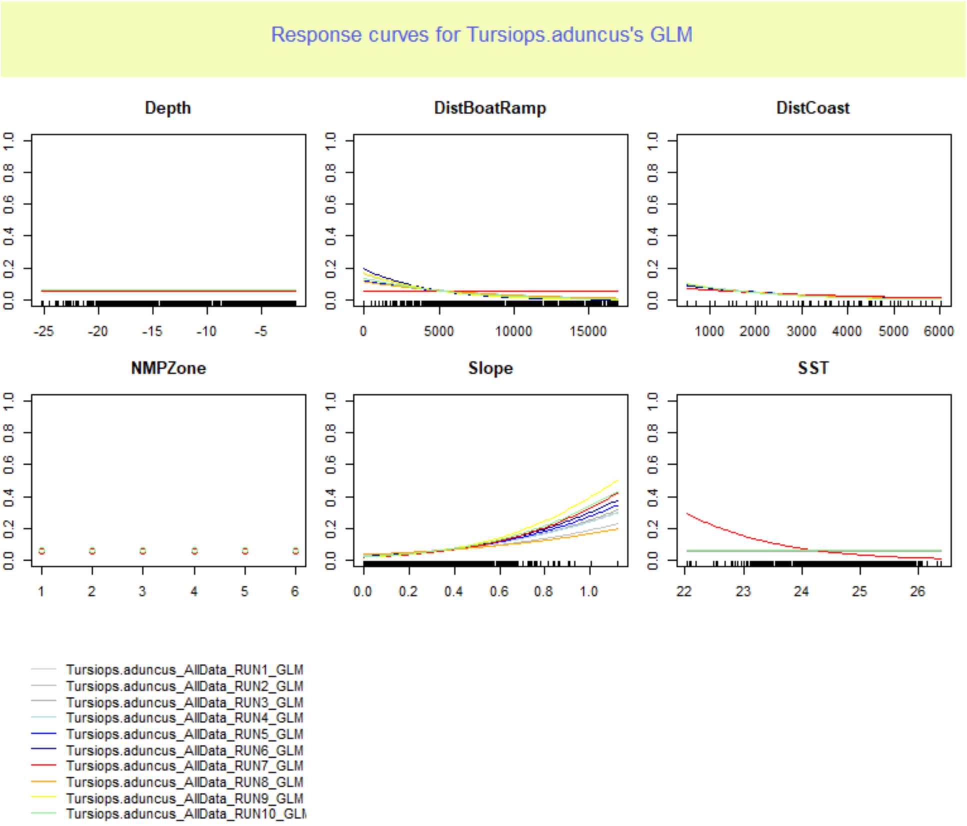
### S2.2.2.2.5 2019 Response curves






Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GAI


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
Tursiops.aduncus_AllData_RUN9_GBM
Tursiops.aduncus_AllData_RUN10_GBI


Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
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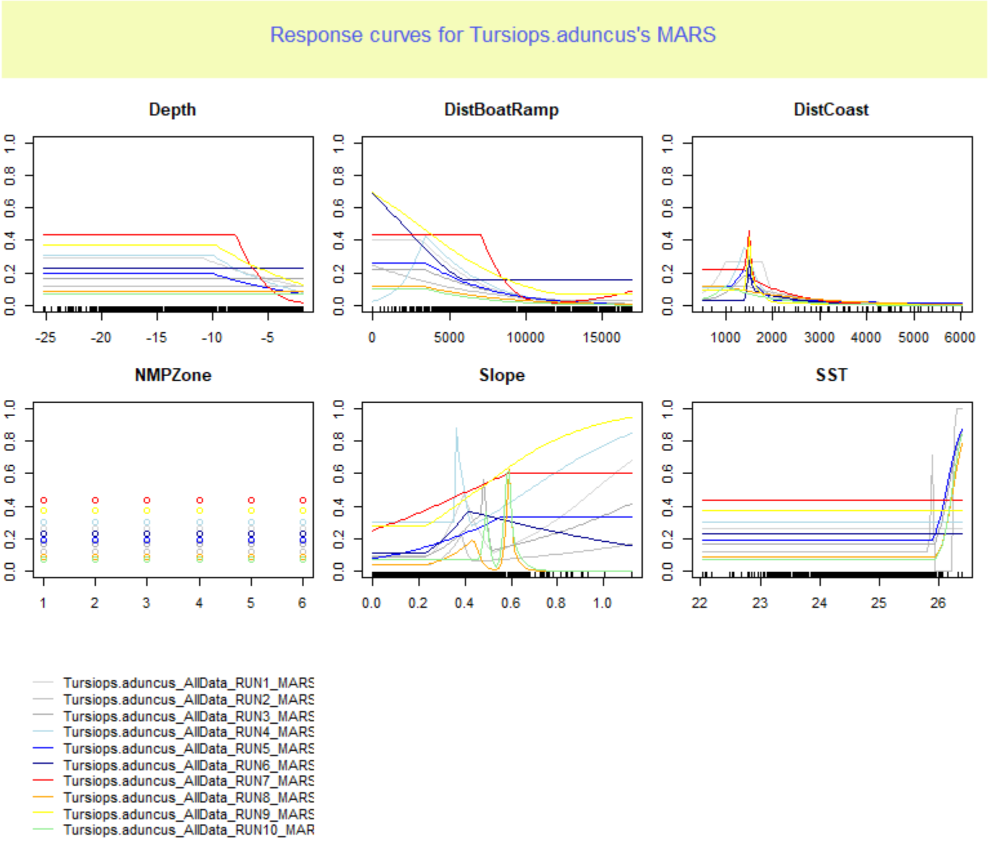
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

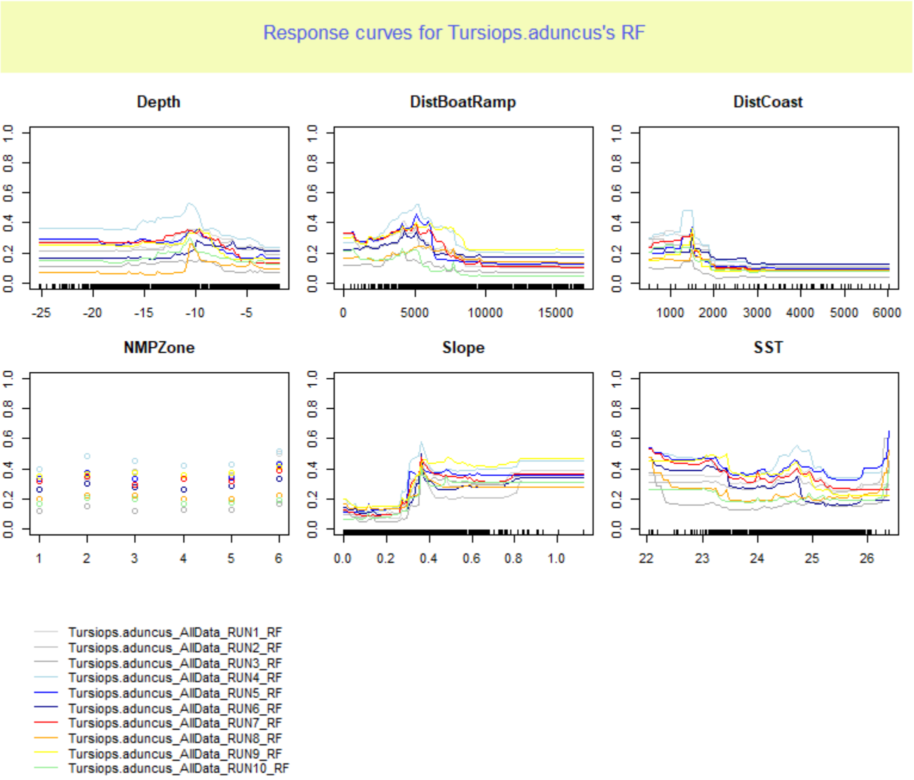


**Figure 8.6:** Response curves of the seven modelling algorithms used in the ensemble to model 2019 Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

### *S2.2.2.3 Distribution and space use maps*

In all five years, the coastal lagoons on the west side, the tip and eastern side of the cape had a moderate probability of occurrence (Figure 8.7). Typically, the highest concentration of moderate to high probability cells were located at the tip and in the waters of Exmouth Gulf to the east of the cape (Figure 8.7).

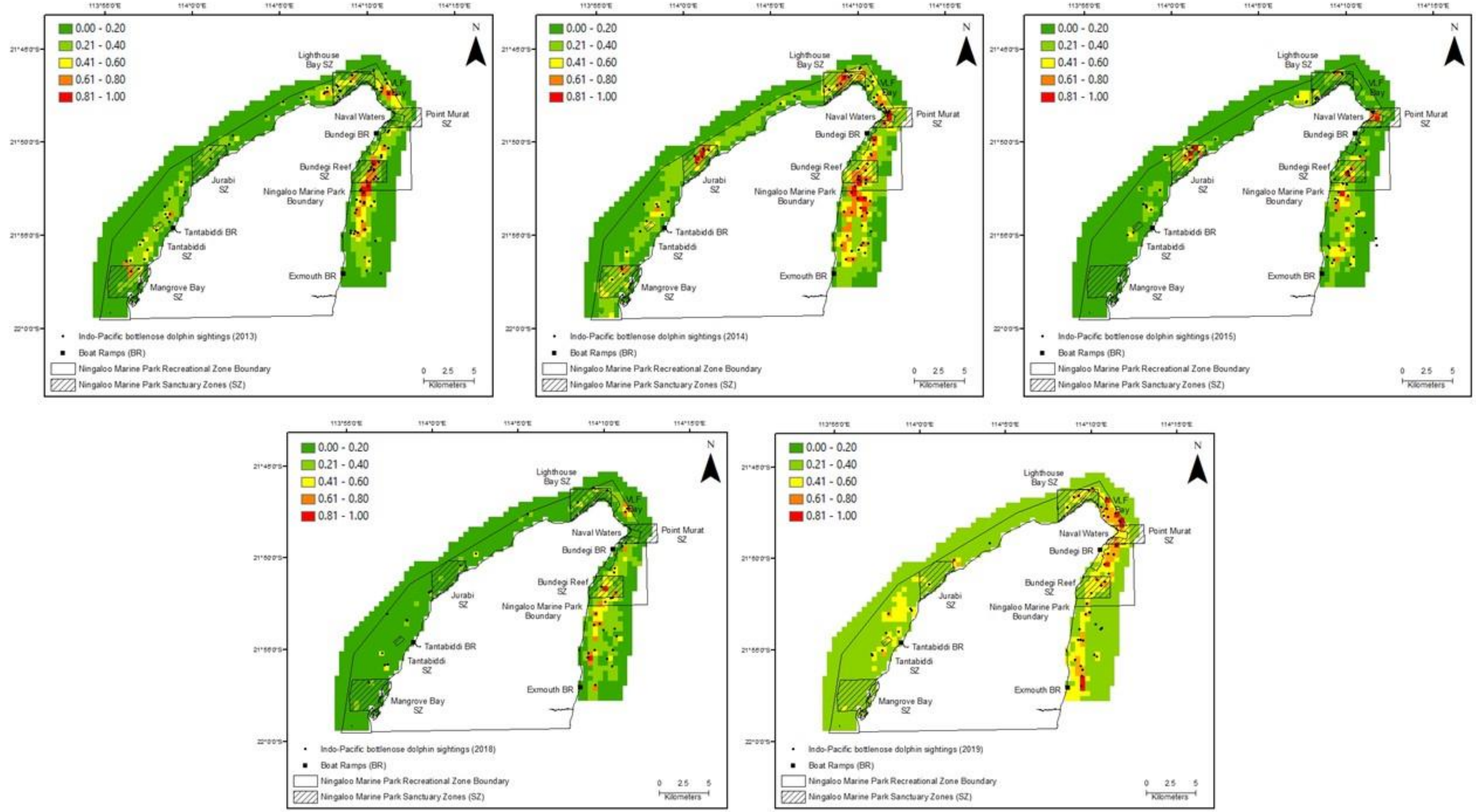


**Figure 8.7:** Ensemble models of Indo-Pacific bottlenose dolphin probability of occurrence at the North West Cape for each survey year (2013, 2014, 2015, 2018 and 2019). Colours as shown in the legend indicate the probability of occurrence 0.00 – 0.40 = low, 0.41 – 0.80 = moderate and 0.81 – 1.00 = high. Outside the recreational zone boundary is the General Use Zone**.**

### *S2.2.3 Results of Ningaloo Marine Park ensemble species distribution models*

After establishing that IP bottlenose dolphin distribution was not influenced by temporal changes, I examined the Ningaloo Marine Park portion of the study area to determine in benthic habitat type (only available for this section of the study area), was influencing space use and distribution.

#### *S2.2.3.1 Model performance*

Most of the single algorithms performed well (AUC > than 0.7, range = 0.43-0.86 and median = 0.73), with the exception of several runs from the ANN algorithm (AUC < 0.7) (Figure S2.8). All poor performing runs were excluded from the final ensemble models. The ensemble model outperformed all single SDMs with an AUC value of 0.95 indicating excellent model performance (Figure 8.8).

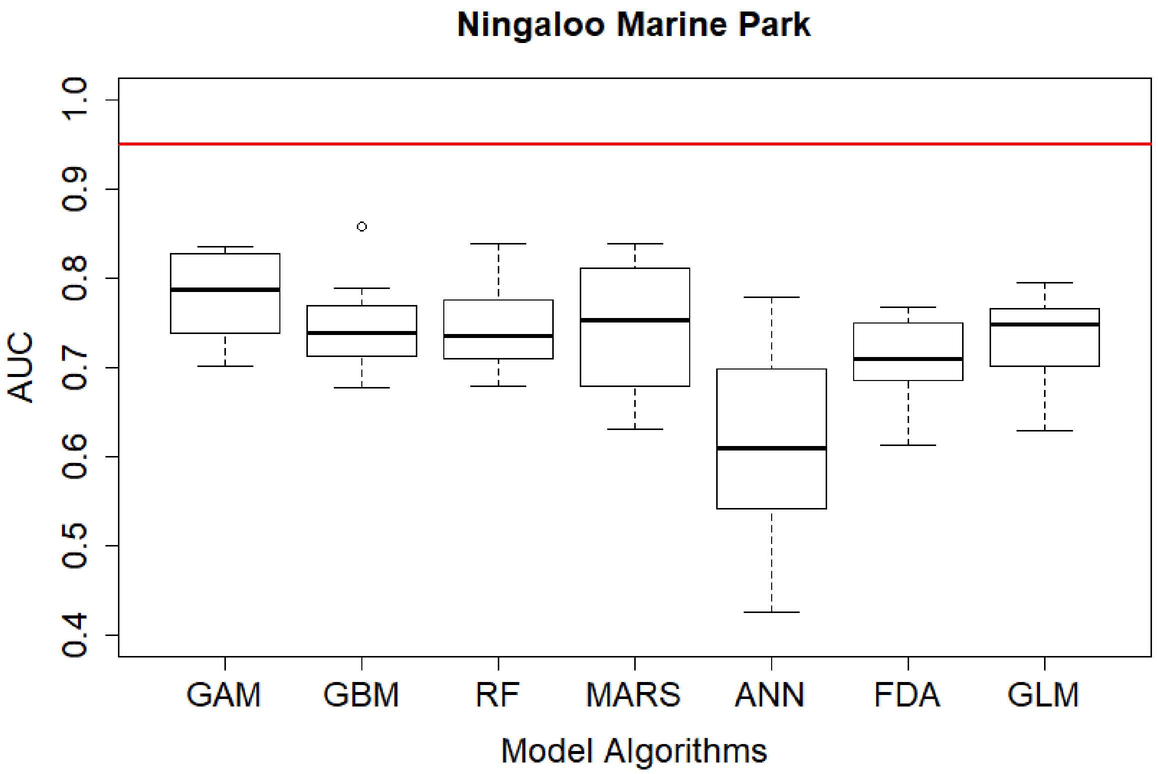


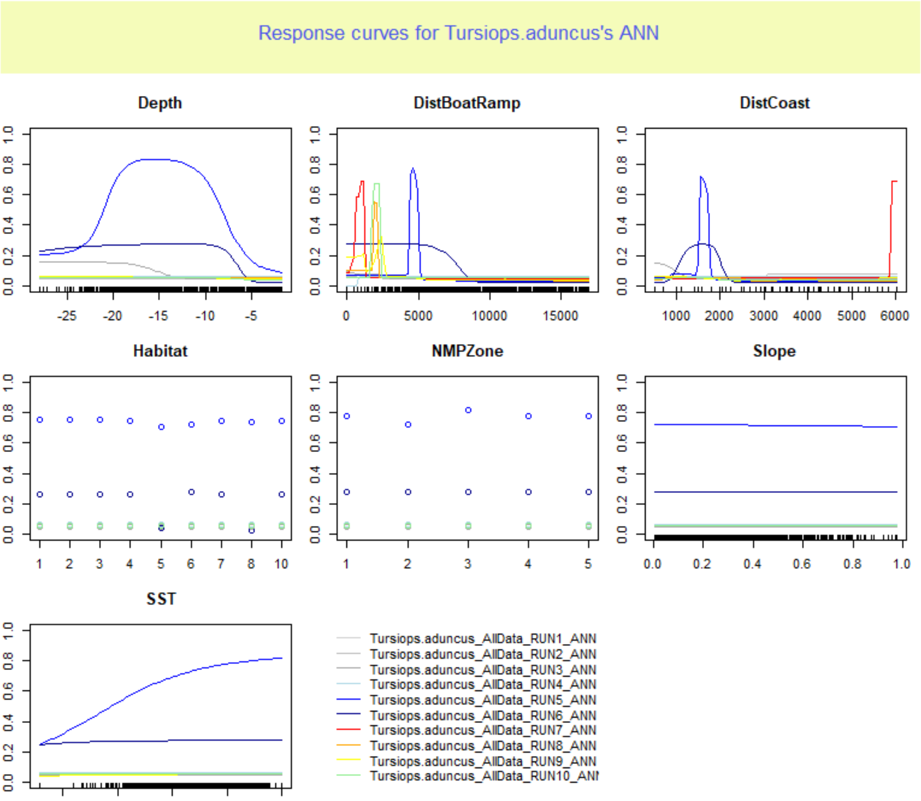
**Figure 8.8:** Performance of the Ningaloo Marine Park species distribution models of Indo-Pacific bottlenose dolphins at the North West Cape, Western Australia. Boxplots for the AUC (area under the curve of the receiver-operating characteristic) of the 10-cross validation runs of each modelling algorithm (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model). The red line shows the AUC of the ensemble model for each year. Values of AUC ≥0.7 indicates that the model predictive performance is moderate to excellent.

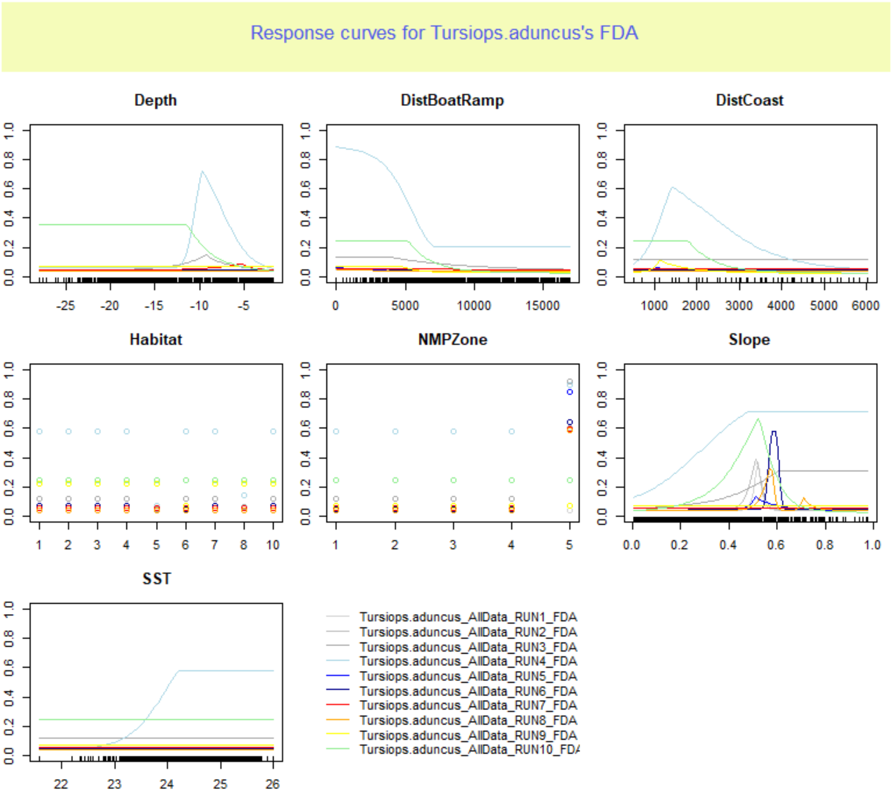
### *S2.2.3.2 Variable importance and response curves*

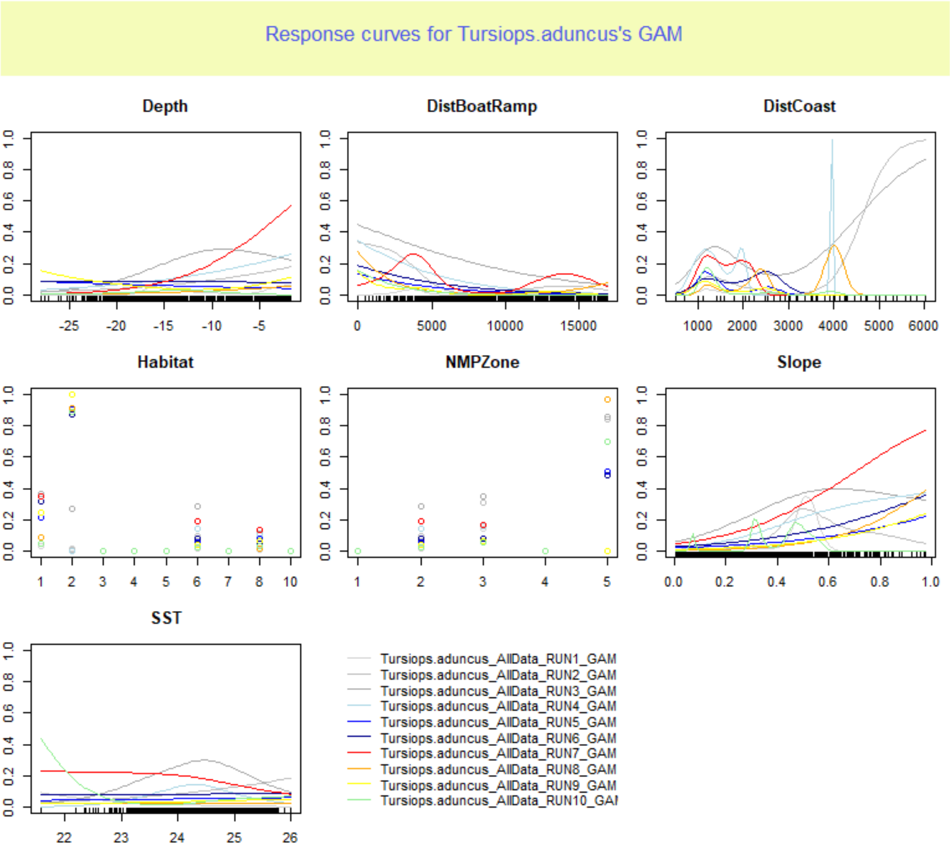
Distance to boat ramp (0.47) and distance to coast (0.38) were the most influential variables explaining IP bottlenose dolphin distribution within the NMP. Habitat type ranked number five out of the seven explanatory variables and on that basis, it was concluded that habitat type was not strongly influencing dolphin distribution (Table 8.3). Response curves indicated that within the NMP, IP bottlenose dolphins were most likely to occur up to 5000 m from the nearest boat ramp and 1000 – 2000 m from the coast (Figure 8.9 in this Appendix).

**Table 8.3:** Importance of predictor variables used in the Ningaloo Marine Park species distribution models (SDMs) of Indo-Pacific bottlenose dolphins (Tursiops aduncus) at the North West Cape, Western Australia. Eight SDM algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), maximum entropy (MaxEnt), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as the ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| **Model** | **Explanatory variables** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** | **Habitat** |
| ANN$^2$ | **0.88** | 0.79 | 0.00 | 0.00 | 0.01 | 0.23 | 0.04 |
| FDA$^7$ | 0.27 | 0.21 | 0.39 | **0.40** | 0.01 | 0.08 | 0.07 |
| GAM$^{10}$ | 0.34 | **0.52** | 0.36 | 0.38 | 0.04 | 0.13 | 0.39 |
| GBM$^8$ | **0.53** | 0.14 | 0.02 | 0.31 | 0.09 | 0.03 | 0.16 |
| GLM$^8$ | **0.40** | 0.11 | 0.41 | 0.19 | 0.03 | 0.02 | 0.07 |
| MARS$^6$ | 0.42 | **0.54** | 0.06 | 0.37 | 0.03 | 0.05 | 0.01 |
| RF$^8$ | **0.29** | 0.13 | 0.04 | 0.20 | 0.10 | 0.07 | 0.11 |
| Mean of means | **0.45** | **0.35** | 0.18 | 0.27 | 0.05 | 0.09 | 0.12 |
| Ensemble | **0.47** | **0.38** | 0.16 | 0.26 | 0.04 | 0.10 | 0.12 |


Response curves for Tursiops.aduncus's ANN


Response curves for Tursiops.aduncus's FDA


Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
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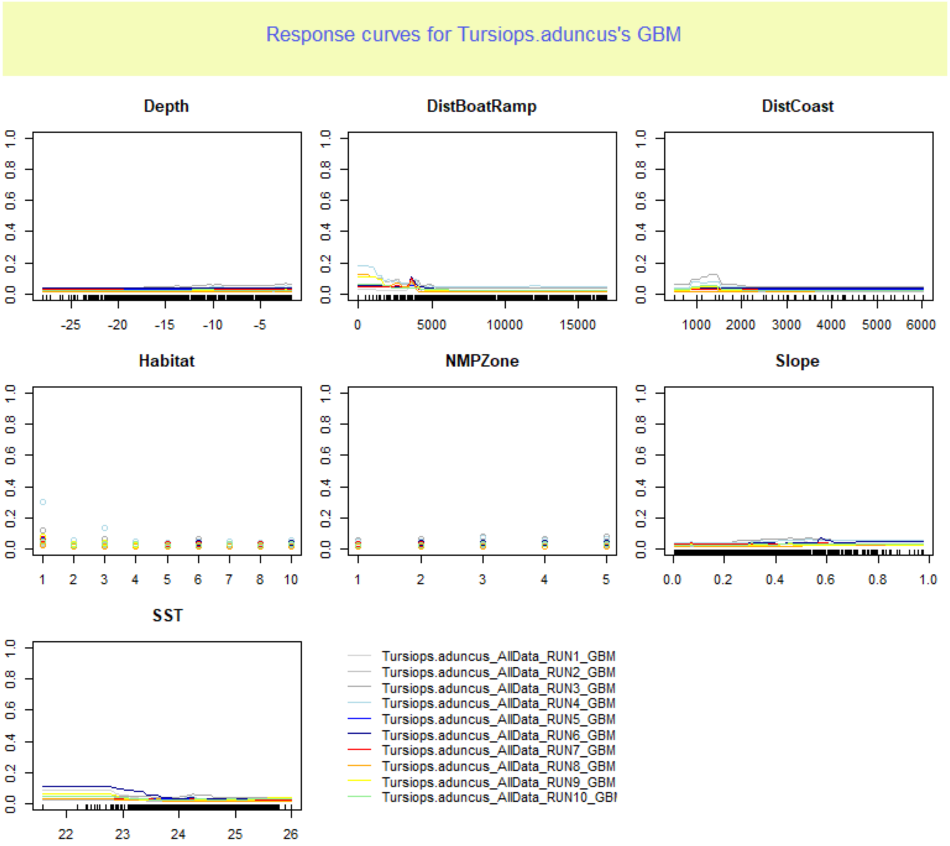
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GAI


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
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0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
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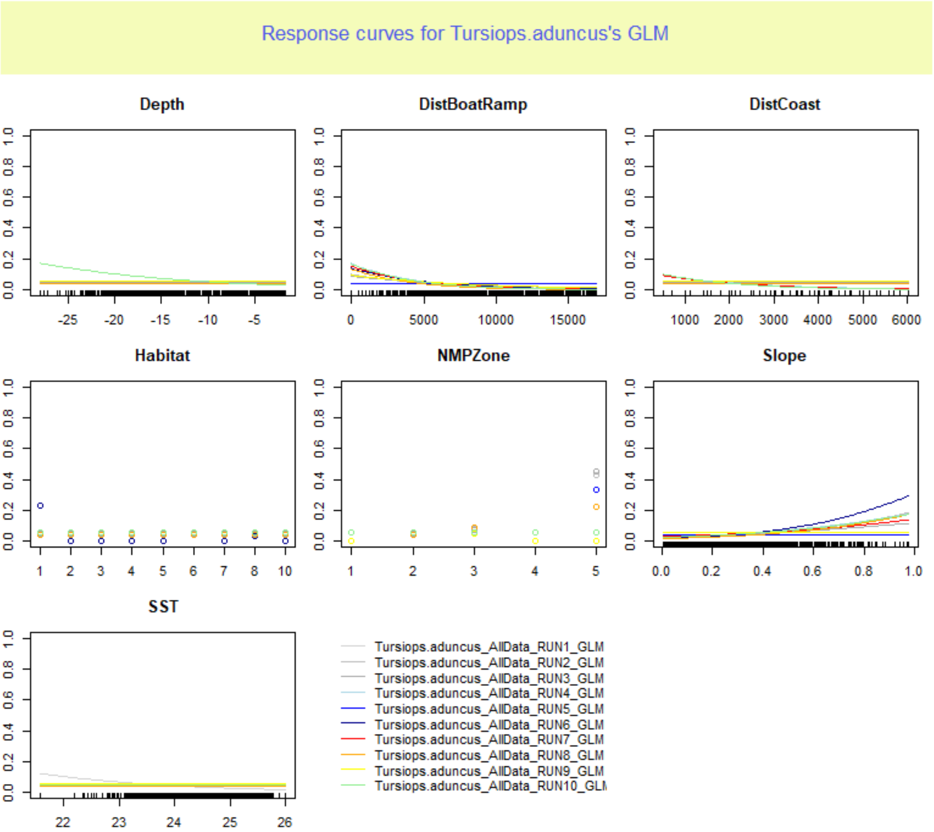
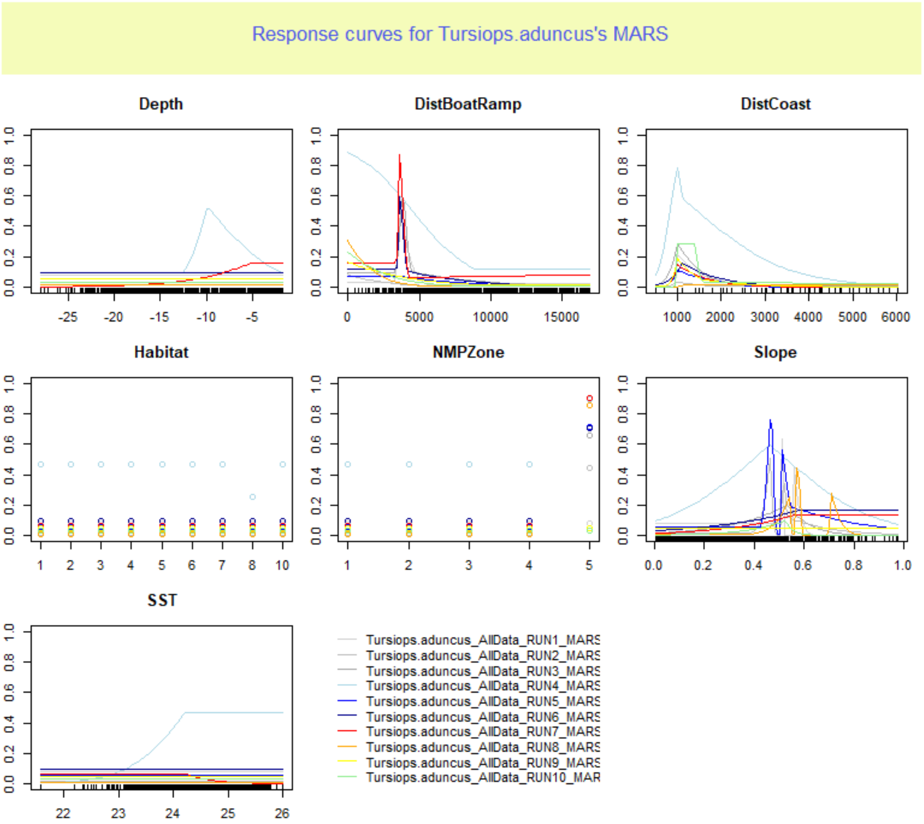

Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
Tursiops.aduncus_AllData_RUN8_GLM
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

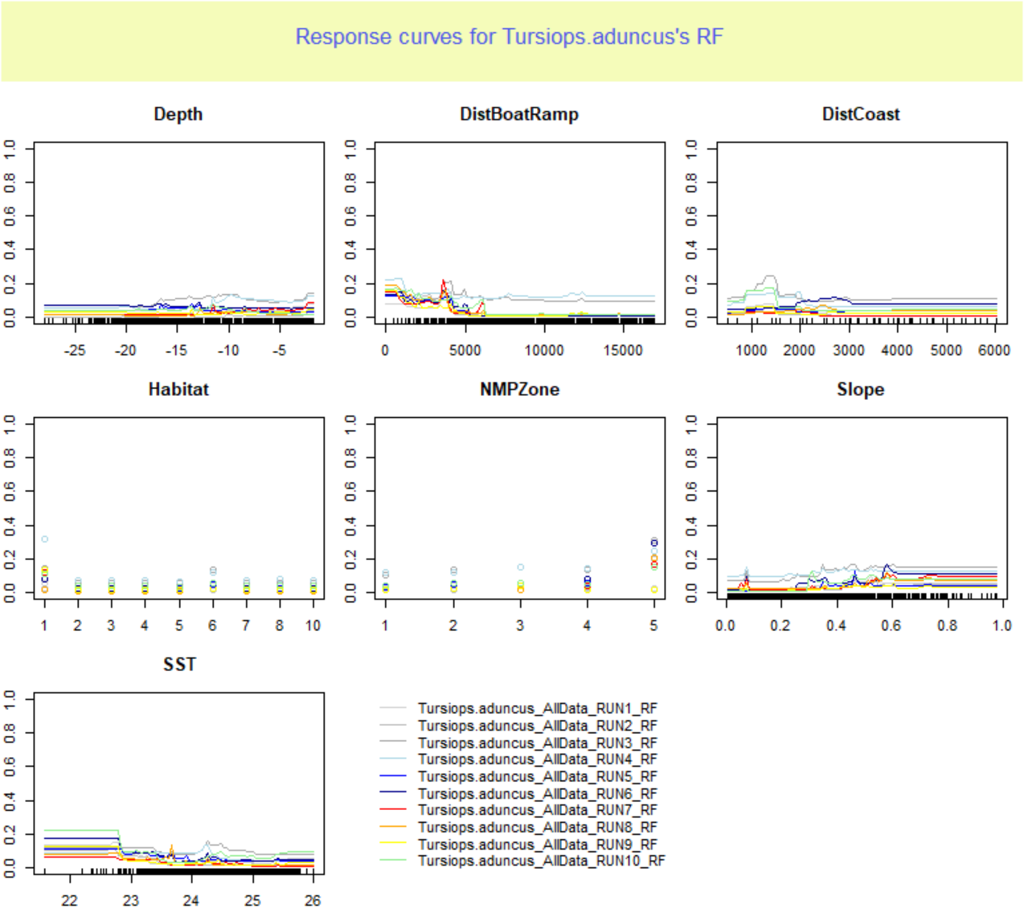


**Figure 8.9:** Response curves of the seven modelling algorithms used in the ensemble to model Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences within the Ningaloo Marine Park at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

### *S2.2.3.3 Distribution and space use maps*

Within the NMP, moderate to high probability of occurrence cells were located in coastal lagoons to the west of the cape, at the tip and waters to the east of the cape, at the top of the Exmouth Gulf (Figure 8.10). One high probability of occurrence cell was modelled, located in the Naval waters.

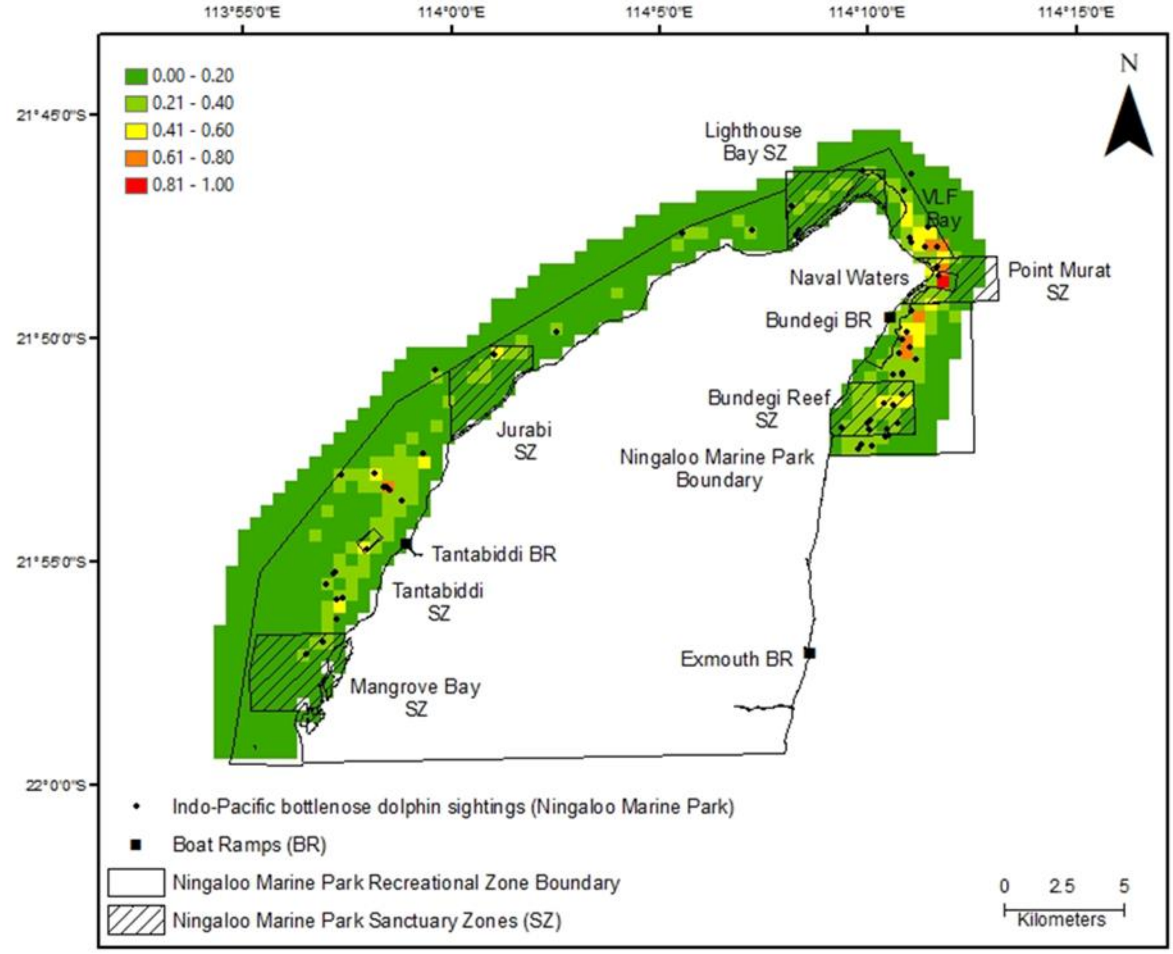


**Figure 8.10:** Ensemble models of Indo-Pacific bottlenose dolphin probability of occurrence at the North West Cape for the Ningaloo Marine Park. Colours as shown in the legend indicate the probability of occurrence 0.00 – 0.40 = low, 0.41 – 0.80 = moderate and 0.81 – 1.00 = high. Outside the recreational zone boundary is the General Use zone.

## S2.3: Habitat type definitions

Habitat type definitions used in the Ningaloo Marine Park species distribution models. Definitions obtained from DPaW. (2006)

Table **8.4**: Habitat type definitions used in the Ningaloo Marine Park ensemble. Definitions obtained from (DPaW., 2006)

| **Habitat Type** | **Definition** |
|---|---|
| Bare reef (intertidal) | The bare reef (intertidal) habitat is located in the intertidal zone (between the LAT and HAT) and may be offshore or contiguous to the coast. This habitat includes low cliffs (<5 m high), high cliffs (>5 m high), boulders (>25.6 cm particle size), or pavement of igneous (granite/basalt), metamorphic (gneiss/schists), or sedimentary (limestone/sandstone) substratum. The bare reef (intertidal) is typically unvegetated but may have algal turfs present. This habitat may contain a variety of mollusc species including oysters (eg. *Saccostrea spp*.), abalone (eg. *Haliotis spp*.) nerites (eg. *Nerita spp. Nodolittorina spp., Littoraria spp*.), chitons (eg. *Ischnochiton spp*.) and barnacles (eg. *Tetraclita porosa*). Rock crabs (*F. Grapsidae*) also inhabit this habitat. |
| Bare reef (subtidal) | Bare reef (subtidal) is located in subtidal areas with either sedimentary (eg. limestone, sandstone), igneous (eg. granite, granophyre) or metamorphic (eg. schist, gneiss) substratum, either as pavement or boulder (>25 cm) fields. This habitat typically includes areas covered by mobile sand veneers, and is located in deep water offshore or in subtidal lagoonal areas. Bare reef (subtidal) habitats are typically bare but may have vegetation (eg. *Thalassodendron spp., Padina spp*.), or have sparse cover sessile invertebrates such as sponges (eg. *Cymbastella spp., Carteriospongia spp*.), octocorals, soft corals and ascidians. |
| Coral reef (intertidal) | The coral reef (intertidal) habitat is located in the intertidal or shallow regions (<1 m LAT) on a limestone substrate. This habitat includes the reef crest, shallow reef fronts, reef flats and shallow back reef zones (see Veron, 2000). Live coral cover varies greatly and some areas have a high proportion of coral rubble. Macroalgae, sand, reef rubble or pavement also may be present. Hard corals (eg. *Acropora spp*.) and soft corals (eg. Sinularia spp.) are typical of the fauna present in these habitats. Parts of this habitat typically support a high diversity and abundance of fish and invertebrate fauna. |
| Coral reef (subtidal) | The coral reef (subtidal) habitat is located in the subtidal zone and often has high live coral cover with macroalgal turf and coralline algae covering areas of reef not occupied |

| | |
|---|---|
| | by living corals. Sand patches, bare pavement and rubble may also be present. This habitat is used to describe the upper seaward reef slope, sheltered back reef, deep lagoonal reef (Veron, 2000) and bommie clusters. Typically, areas of high coral cover are generally restricted to water depths of less than 15 m depth. Offshore, the coral reef (subtidal) habitats are dominated by the faster growing coral species such as Acropora (eg. *A. hyacinthus*) and Pocillopora (eg. *P. verrucosa*). This habitat typically supports a high diversity and abundance of fish and other coral reef fauna such as crabs (Families Xanthidae and Portunidae) and snapping shrimp (*Alpheus spp*.). |
| Macroalgae | The macroalgae (subtidal) habitat is subtidal areas with sedimentary, igneous or metamorphic substratum of low or high relief. This habitat is found in deep and shallow-waters and also may incorporate mobile sand patches, and scattered isolated hard and soft corals. This habitat generally is covered in large fleshy macroalgae (eg. *Sargassum spp*., *Cystophora spp., Ecklonia spp*.) or macroalgal turf (thallus height <100mm) comprised of red (eg. *Laurencia spp*.), green (eg. *Enteromorpha spp., Ulva spp. Caulerpa spp*.) and brown (eg. *Padina spp., Turbinaria spp.)* algae. A wide range of invertebrate life such as sponges, ascidians, gastropods, seastars, brittle stars, sea urchins and soft corals, are associated with this habitat. Crustaceans such as the western rock lobster (*Panulirus cygnus*), painted rock lobster (*P. vericolor*), ornate rock lobster (*P. ornatus*) and the southern rock lobster (*Janus edwardsii*) are often found in macroalgae (subtidal) habitats. |
| Mangroves | The mangrove habitat describes areas of mangrove forest greater than 0.05 ha and typically is located in the upper intertidal zone. The substratum of this habitat is typically comprised of mud and silt; however some mangrove species do occur on intertidal rocky shores. In Western Australia, the most common mangrove species are *Rhizophora stylosa* and *Avicennia marina*, the latter occurring as far south as Bunbury. Mangrove roots provide a substratum for many gastropods (eg. *Natica sp., Cerithium sp., Strombus spp*.) and other invertebrates, such as the mangrove crab (*Scylla serrata and Scylla olivacea*) and fiddler crab (*Uca sp*.)are often present. Mangals are an important habitat for birds such as the mangrove whistler (*Pachycephala melanura*) and brahminy kite (*Haliastur indus*). |
| Mobile sand | The mobile sand (subtidal) habitat is defined as subtidal habitats that have predominantly white carbonate sands (0.1-2 mm grain size) as a substrate, which is constantly being moved by currents or wave action. However, the sand may overlay |

| | |
|---|---|
| | reef platform or have patches of other habitats present. Mobile sand (subtidal) habitats typically are bare, and may have seasonal vegetation or permanent patches of seagrass or macroalgae. Invertebrate infauna such as scallops (eg. *Pecten spp*.) seastars (eg. *Astropecten spp*.), and sea urchins (eg. *Brissus spp., Echinocardium spp*.), may also be present. |
| Pelagic | The pelagic habitat is defined as habitats with greater than 50 m depth. The pelagic habitat is dominated by the life in the water column, which include pelagic fish, pelagic invertebrates, zooplankton and phytoplankton. Contemporary acoustic mapping techniques have been able to discern hardness (soft and hard) and relief (smooth and rough) which may be used for local scale habitat mapping (*Penrose & Siwabessy, 2001; Siwabessy et al., 1999*). |
| Saltmarsh | The saltmarsh habitat describes areas of low relief located in the upper intertidal zone of low energy coastlines. The substratum consists of muddy or silty terrigenous sediment. Saltmarsh habitats often occur landward of mangals, tidal creeks and estuaries, and typically supports vegetation such as the saltwater couch (Sporobolus virginicus) and blue-green algal mats (eg. *Microcoleus chthonoplastes, Oscillotoria sp., Phoridium sp*.), but can also occur as unvegetated coastal saline flats. In the tropics, burrowing crabs (*Uca sp*.), soldier crabs (*Mictyris sp*.) and *Cerinthium spp*. gastropods are conspicuous fauna in this habitat. In temperate areas, the glassswort *Sarcocornia quinqueflora* and *Sporobolus virginicus* are conspicuous flora in this habitat. |

## S2.4: Biomod2 algorithm default settings

Artificial Neural Network (ANN) = NbCV = 5, size = NULL,decay = NULL, rang = 0.1, maxit = 200

Flexible Discriminant Analysis (FDA) = method = 'mars', add_args = NULL

Generalised Additive Modelling (GAM) = algo = 'GAM_mgcv',type = 's_smoother', k = -1, interaction.level = 0, myFormula = NULL, family = binomial(link = 'logit'), method = 'GCV.Cp',optimizer = c('outer','newton'), select = FALSE, knots = NULL,paraPen = NULL, control = list(nthreads = 1, irls.reg = 0, epsilon = 1e-07, maxit = 200, trace = FALSE, mgcv.tol = 1e-07, mgcv.half = 15, rank.tol = 1.49011611938477e-08, nlm = list(ndigit=7, gradtol=1e-06, stepmax=2, steptol=1e-04, iterlim=200, check.analyticals=0), optim = list(factr=1e+07), newton = list(conv.tol=1e-06, maxNstep=5, maxSstep=2, maxHalf=30, use.svd=0), outerPIsteps = 0, idLinksBases = TRUE, scalePenalty = TRUE, efs.lspmax = 15, efs.tol = 0.1, keepData = FALSE, scale.est = fletcher, edge.correct = FALSE)

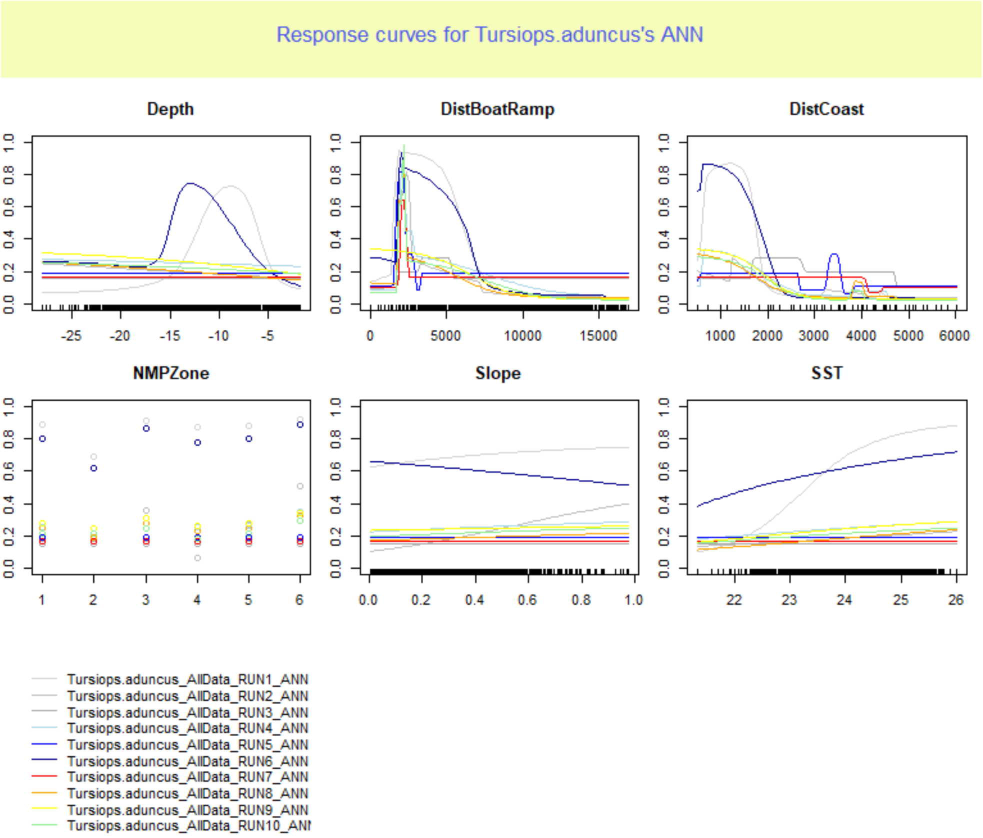
Generalised Boosted Modelling (GBM) = distribution = 'bernoulli',n.trees = 2500,interaction.depth = 7,n.minobsinnode = 5,shrinkage = 0.001,bag.fraction = 0.5,train.fraction = 1,cv.folds = 3,keep.data = FALSE,verbose = FALSE, perf.method = 'cv',n.cores = 1)

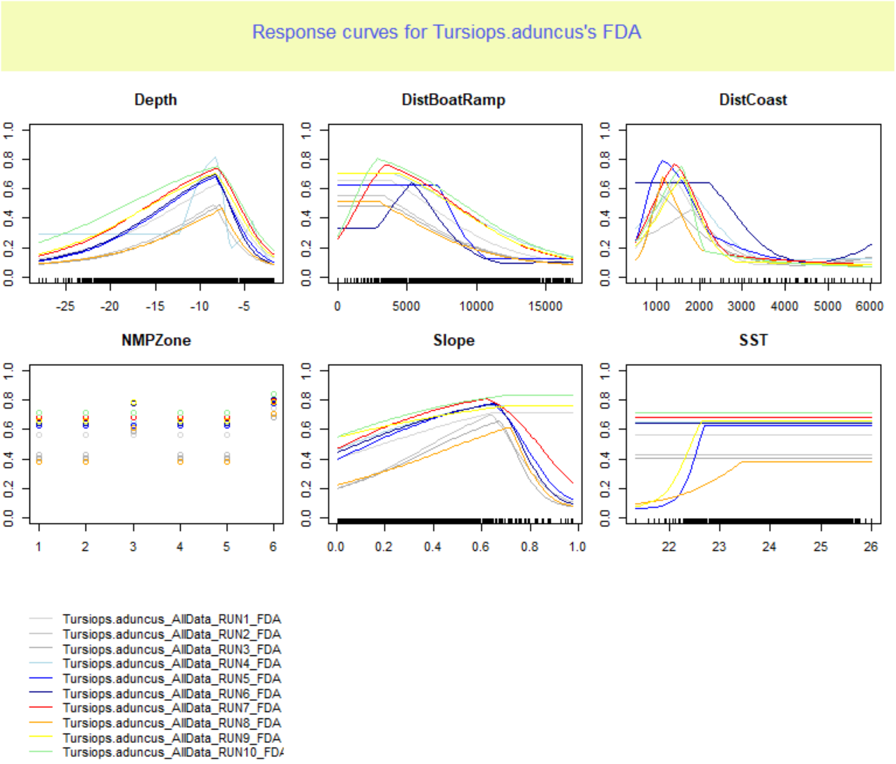
Generalised Linear Modelling (GLM) = type = 'quadratic',interaction.level = 0, myFormula = NULL,test = 'AIC', family = binomial(link = 'logit'), mustart = 0.5, control = glm.control(epsilon = 1e-08, maxit = 50, trace = FALSE) )

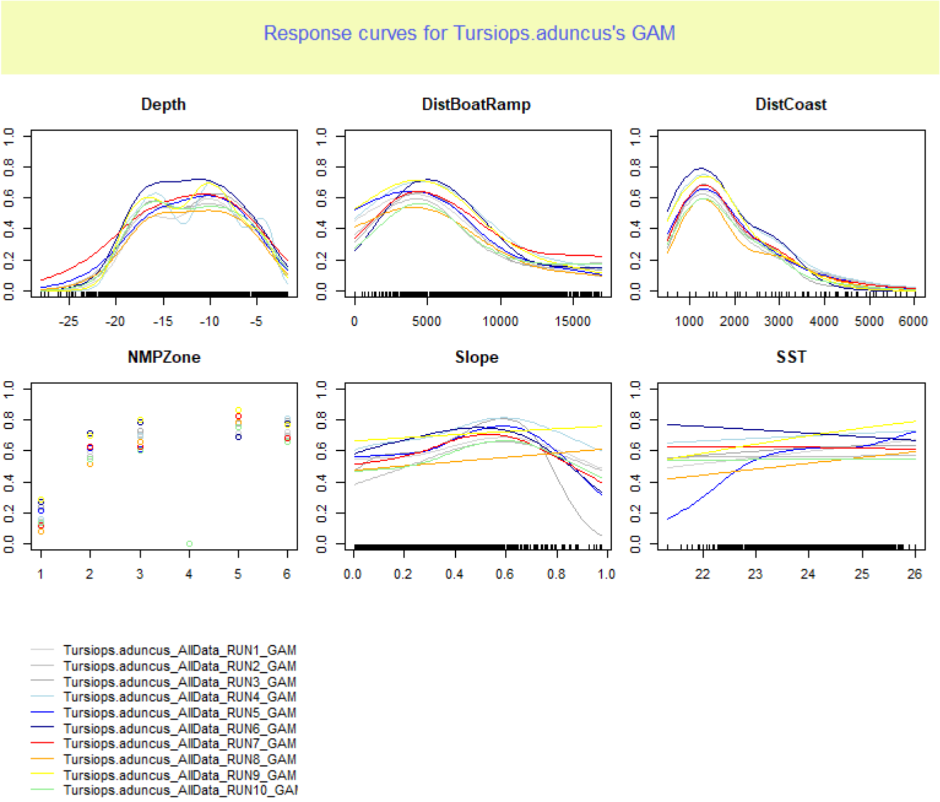
Multivariate Adaptive Regression Splines (MARS) = type = 'simple', interaction.level = 0, myFormula = NULL, nk = NULL, penalty = 2, thresh = 0.001, nprune = NULL, pmethod = 'backward')

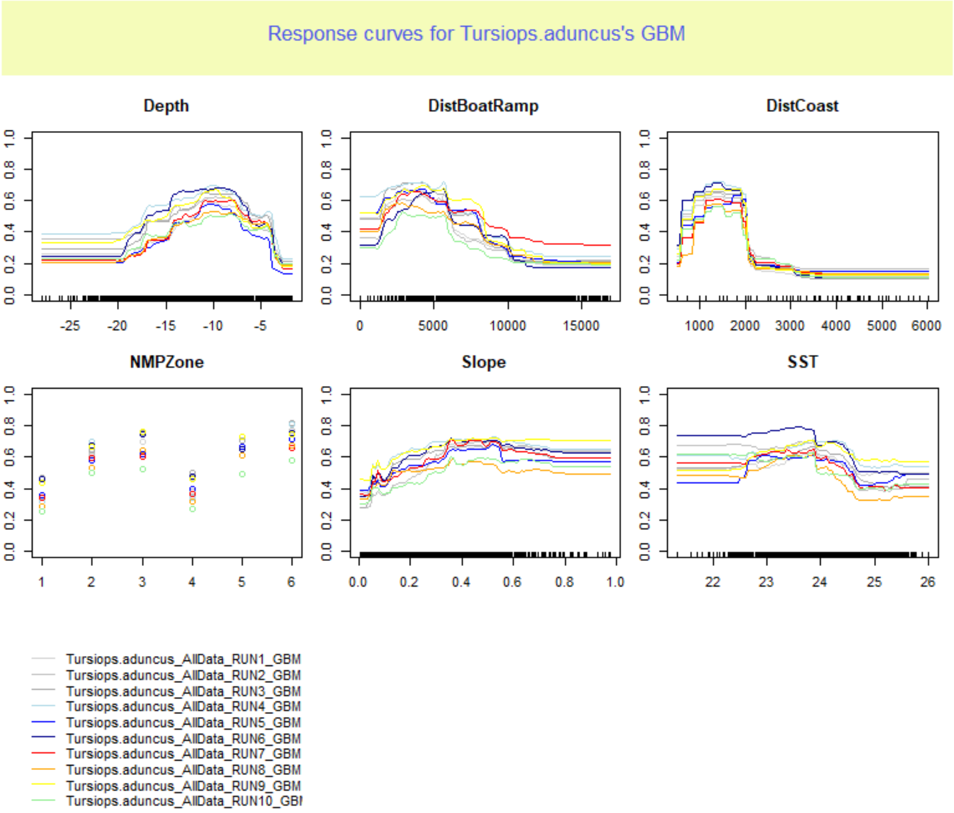
Random Forest (RF) = do.classif = TRUE, ntree = 500, mtry = 'default', nodesize = 5, maxnodes = NULL)

## *S2.5: Overall (all data combined) ensemble response curves (entire study area)*






Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GA


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
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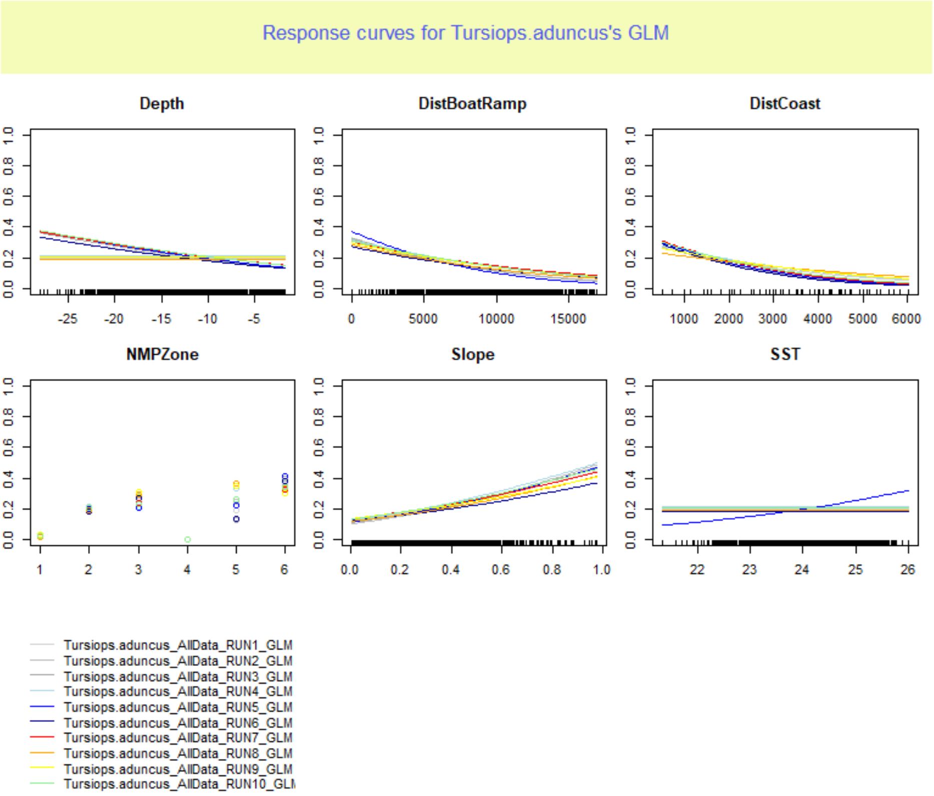
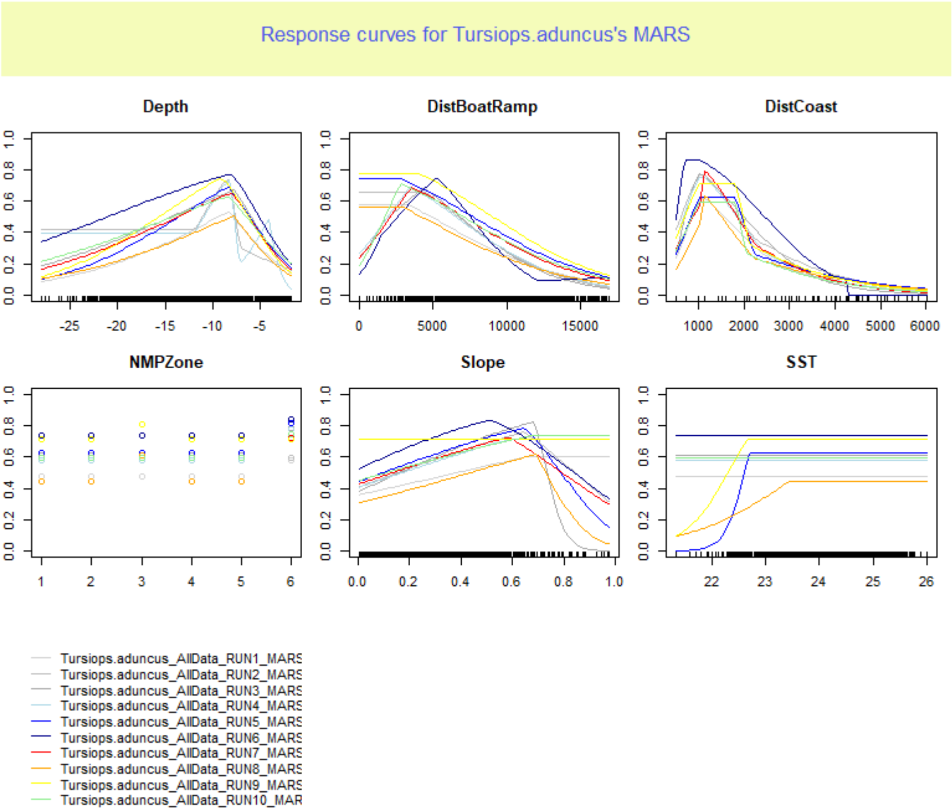
Tursiops.aduncus_AllData_RUN10_GB


Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
Tursiops.aduncus_AllData_RUN8_GLM
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

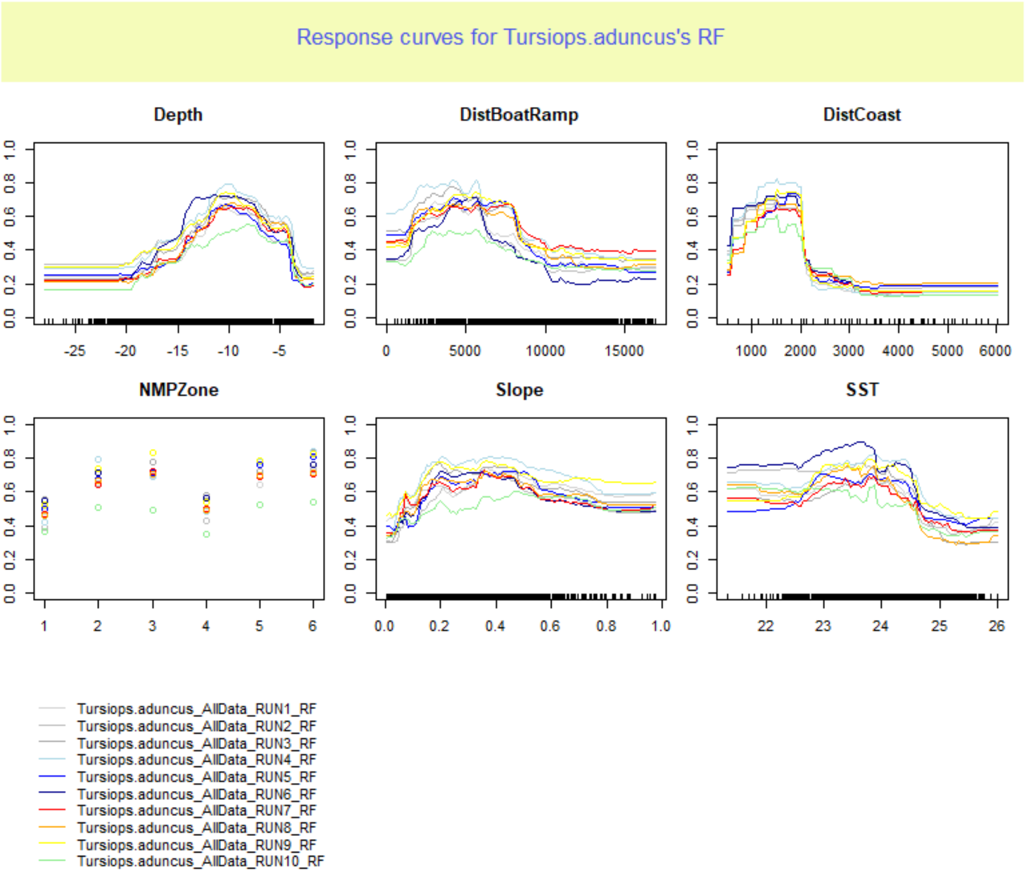
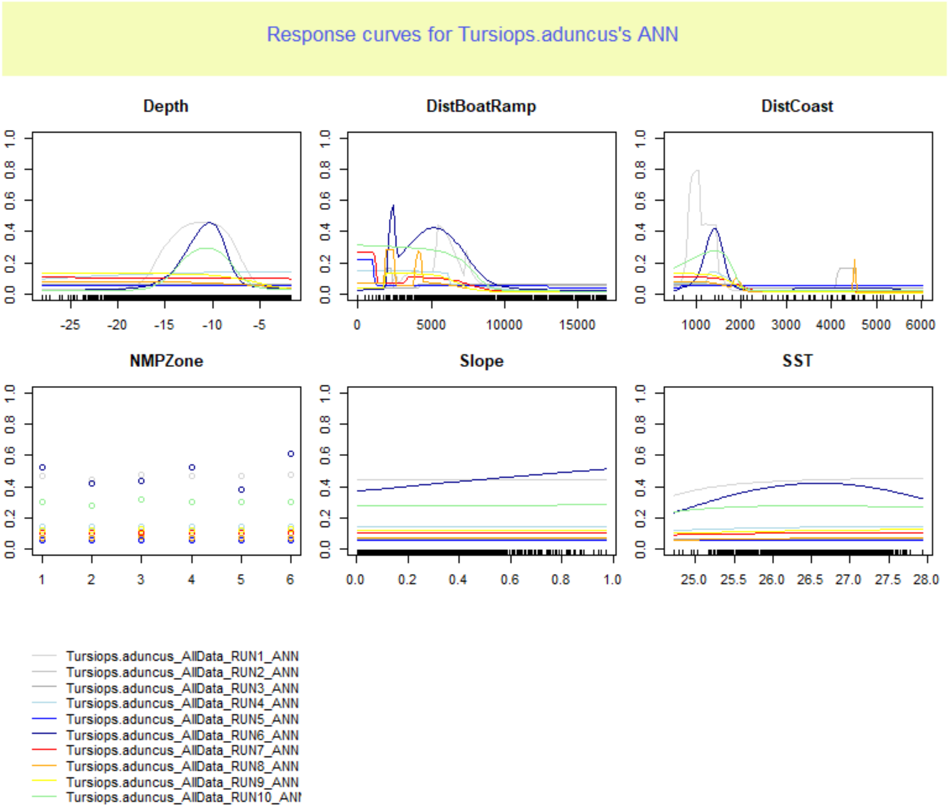
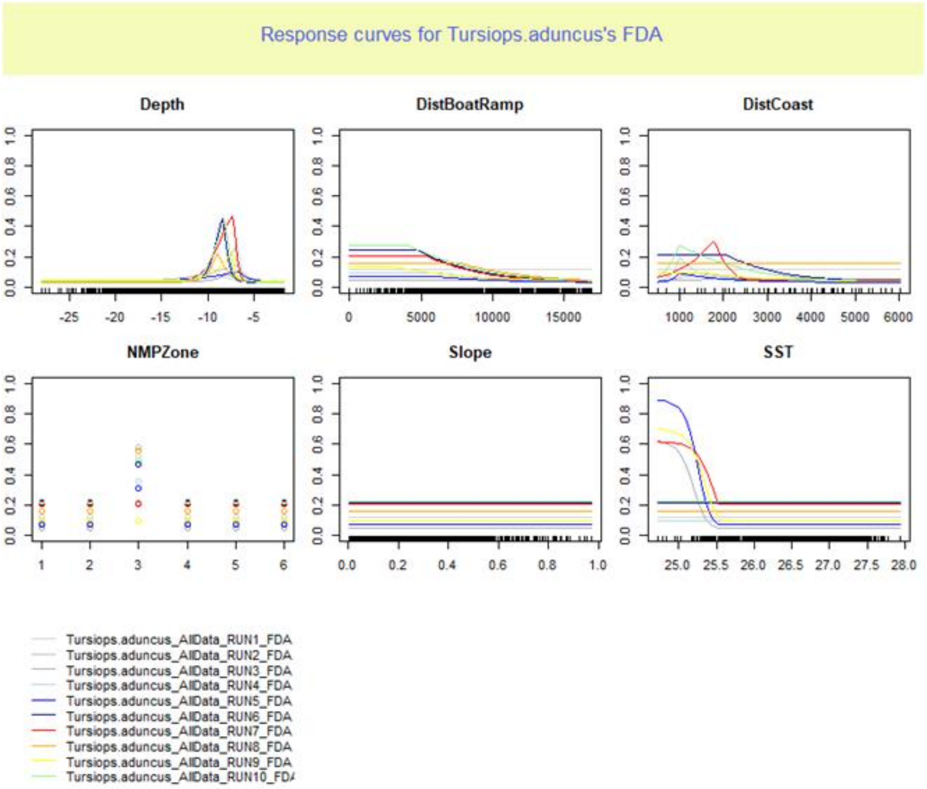


**Figure 8.11:** Response curves of the seven modelling algorithms used in the ensemble to model overall Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

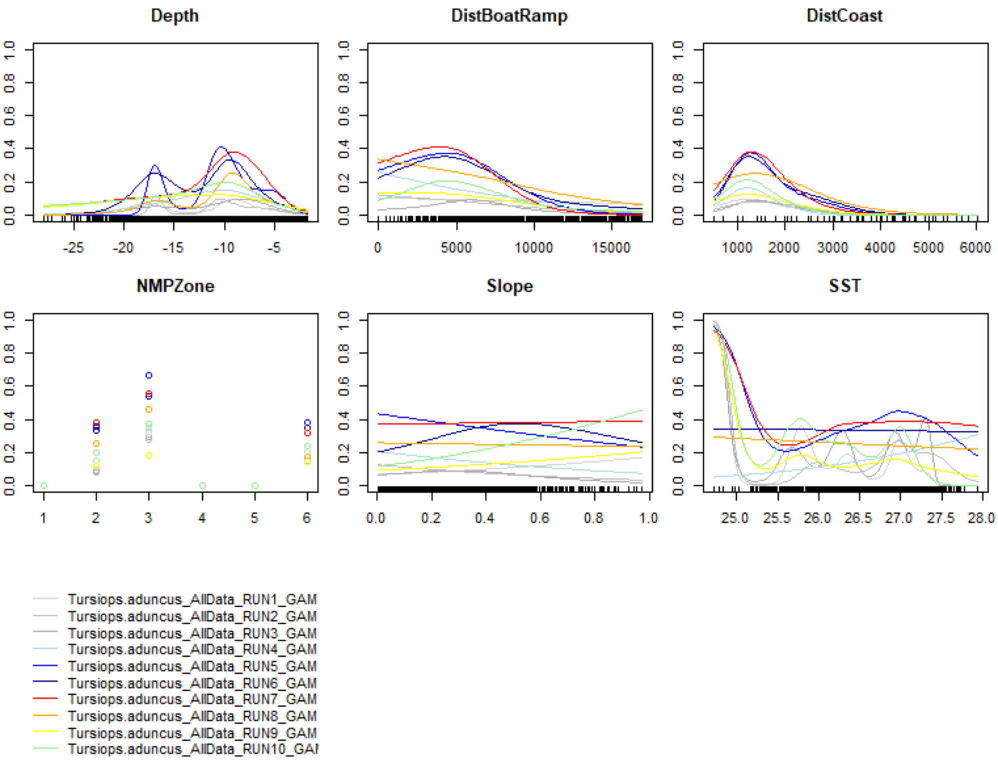
## S2.6: *Seasonal ensemble response curves (entire study area)*

### *S2.6.1 Autumn response curves (entire study area)*

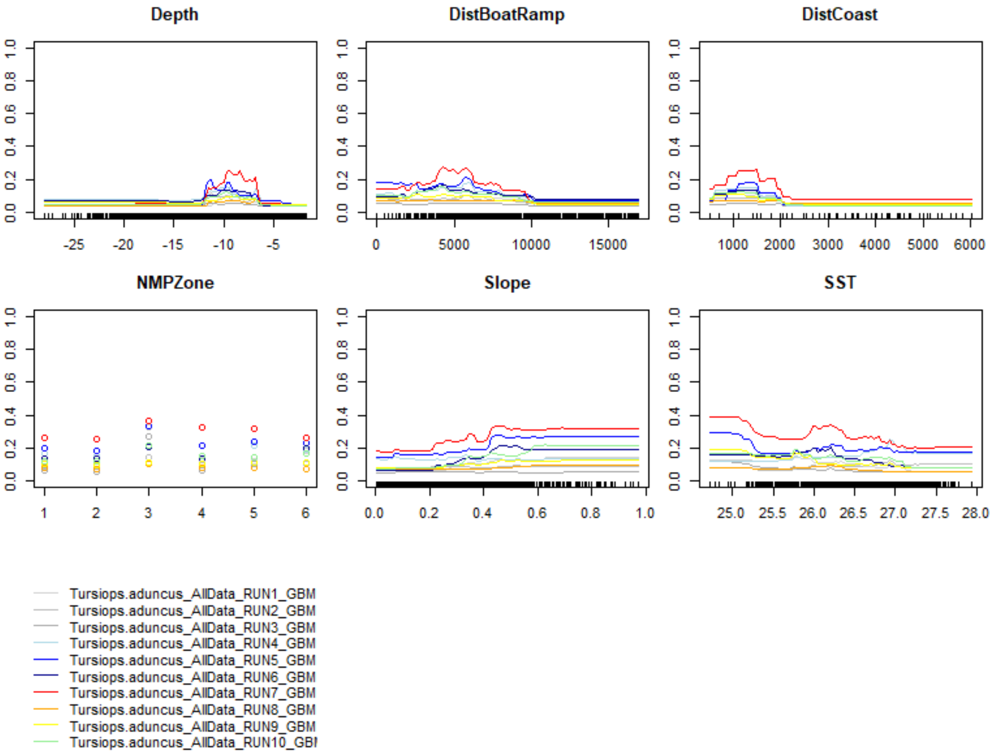


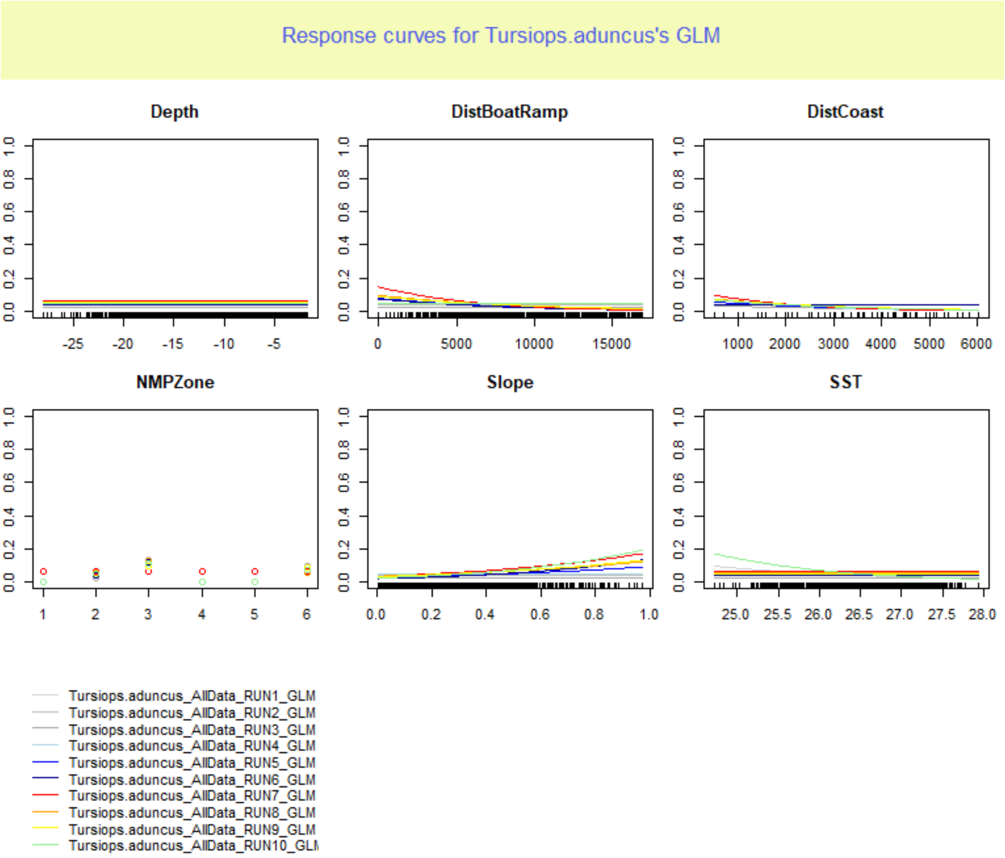


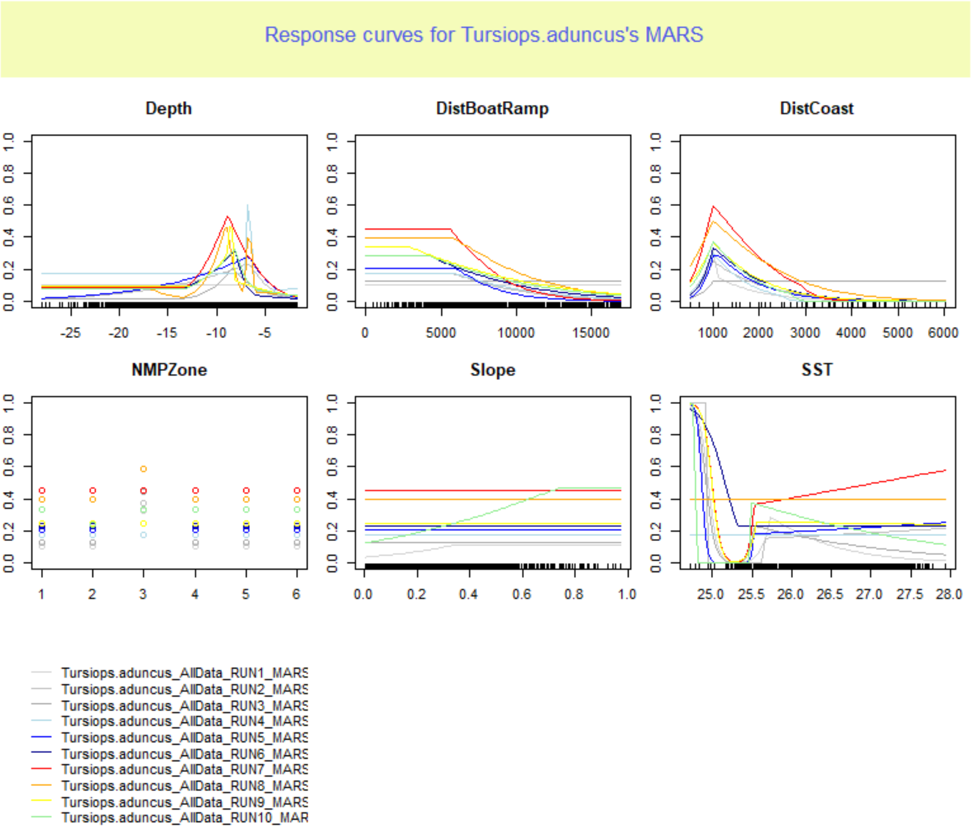
## Response curves for Tursiops.aduncus's GAM



## Response curves for Tursiops.aduncus's GBM




Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
25.0
25.5
26.0
26.5
27.0
27.5
28.0
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
Tursiops.aduncus_AllData_RUN8_GLM
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
25.0
25.5
26.0
26.5
27.0
27.5
28.0
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

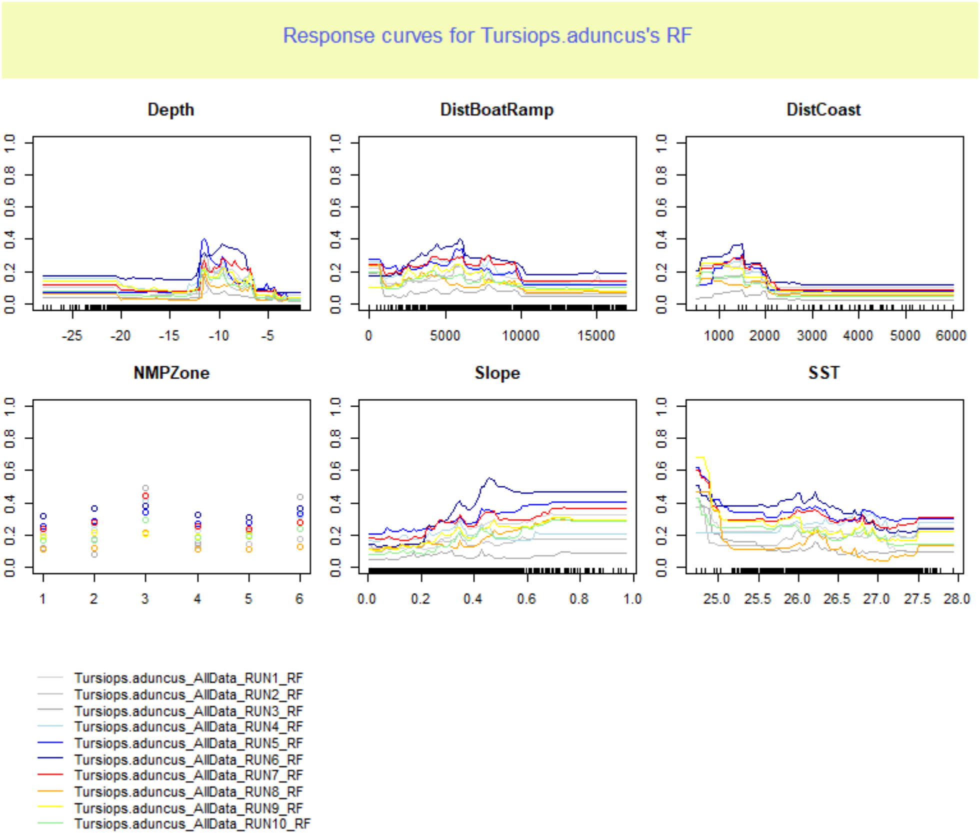
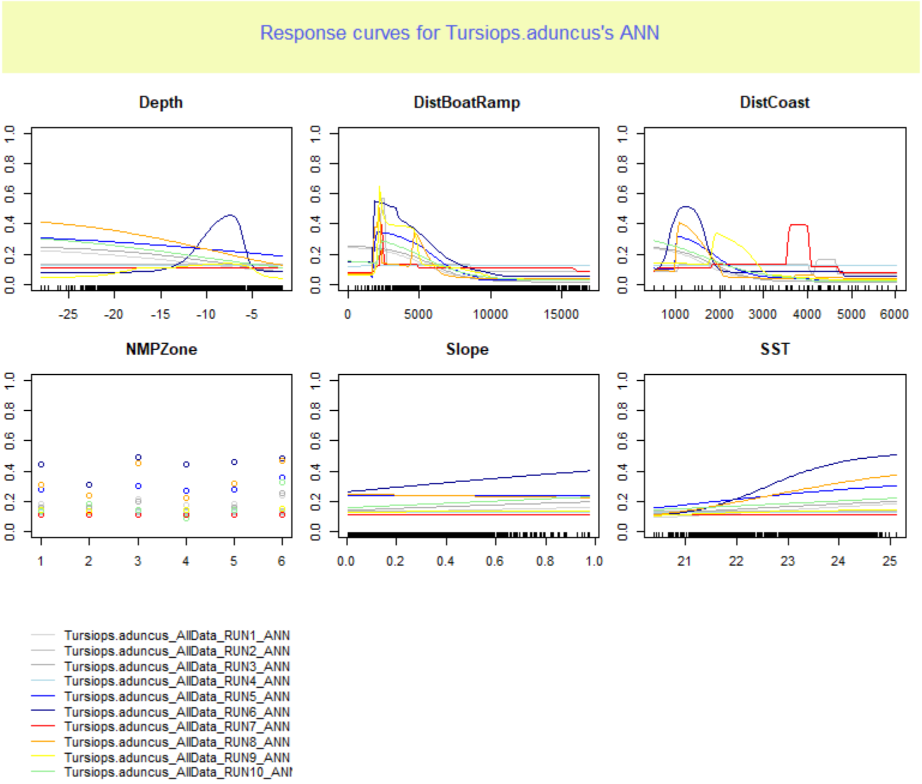
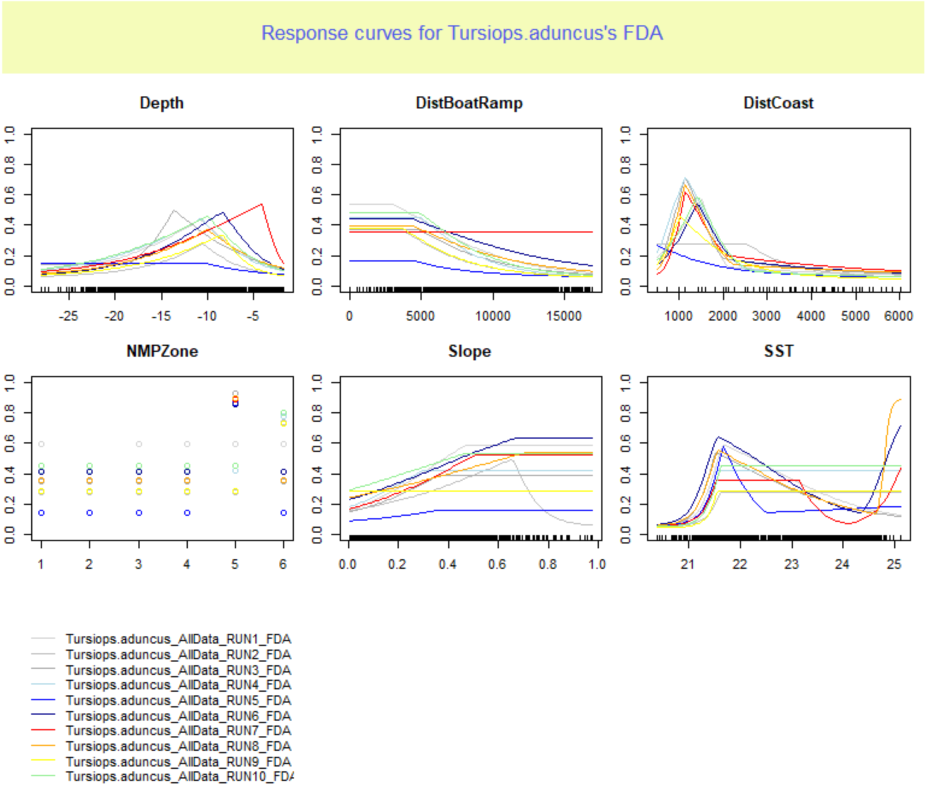


**Figure 8.12:** Response curves of the seven modelling algorithms used in the ensemble to model autumn Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

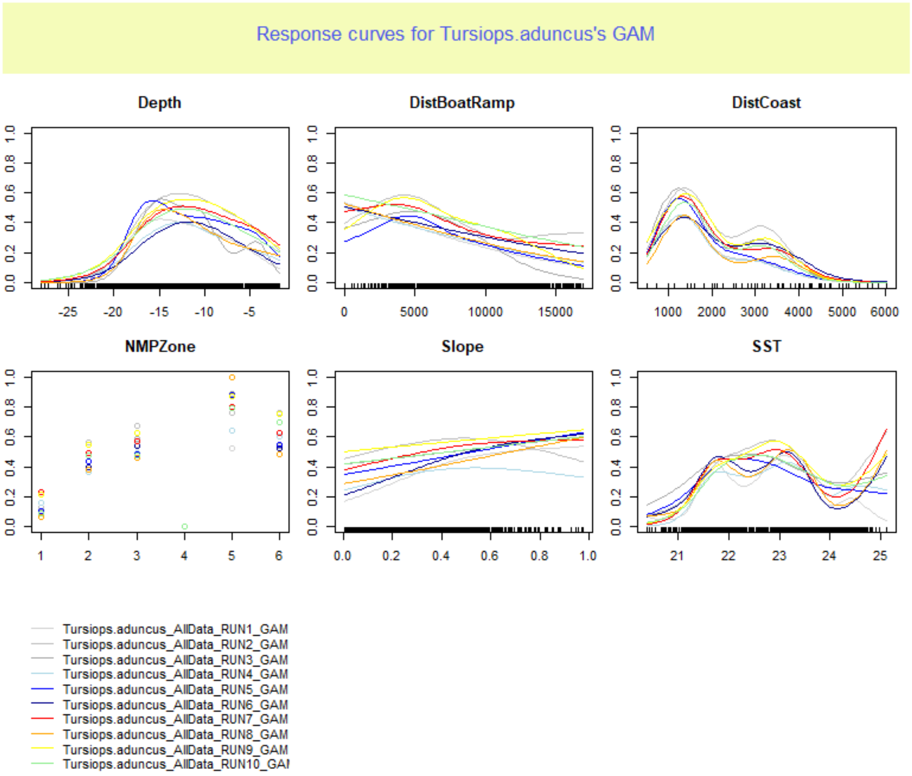
### *S2.6.2 Winter response curves (entire study area)*



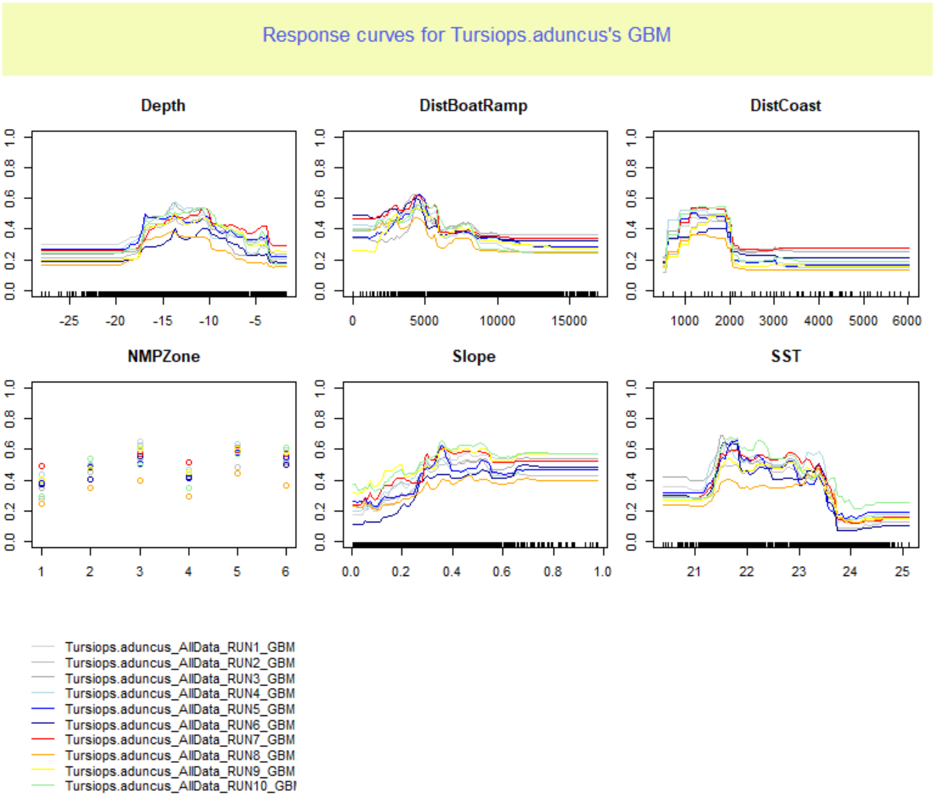
Response curves for Tursiops.aduncus's ANN



Response curves for Tursiops.aduncus's FDA

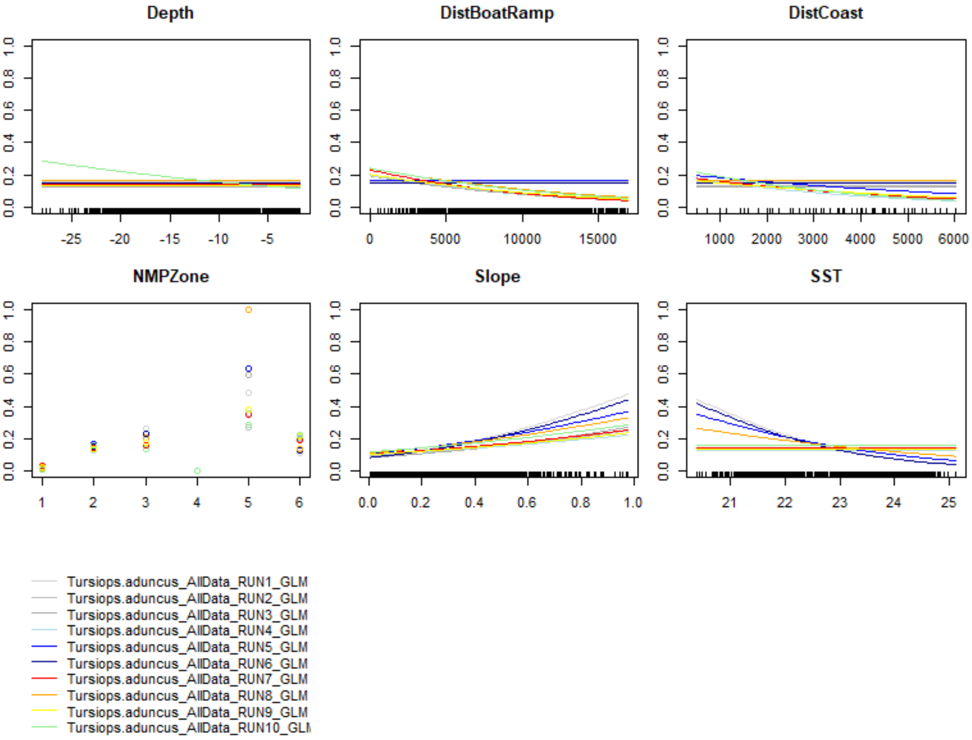


Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
21 22 23 24 25
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GAI

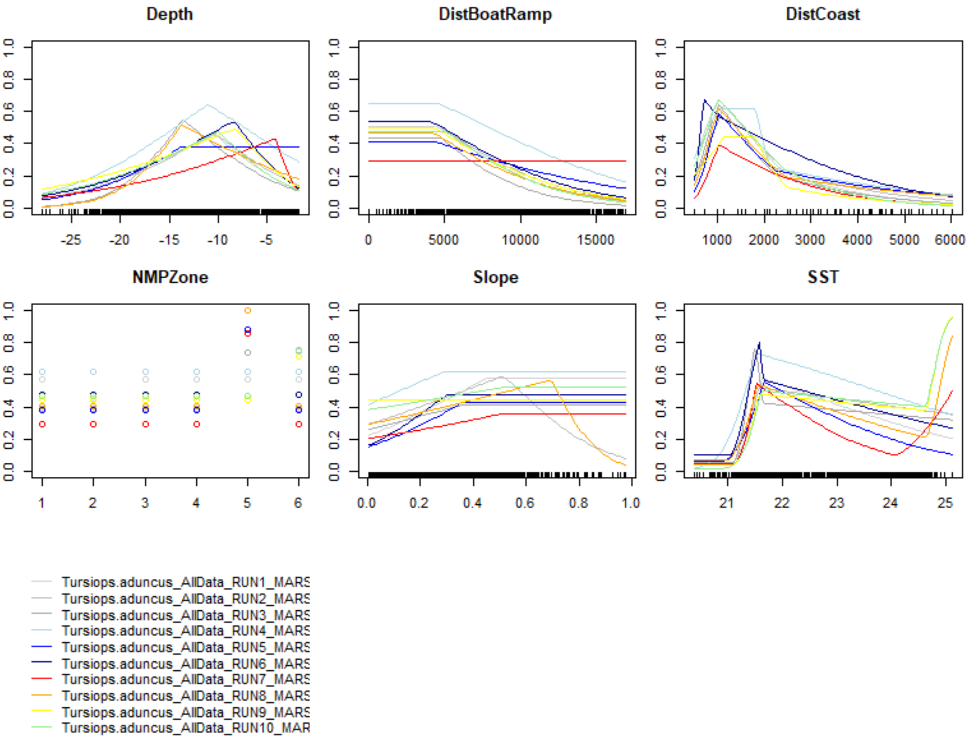


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
21 22 23 24 25
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
Tursiops.aduncus_AllData_RUN9_GBM
Tursiops.aduncus_AllData_RUN10_GBI

## Response curves for Tursiops.aduncus's GLM



## Response curves for Tursiops.aduncus's MARS



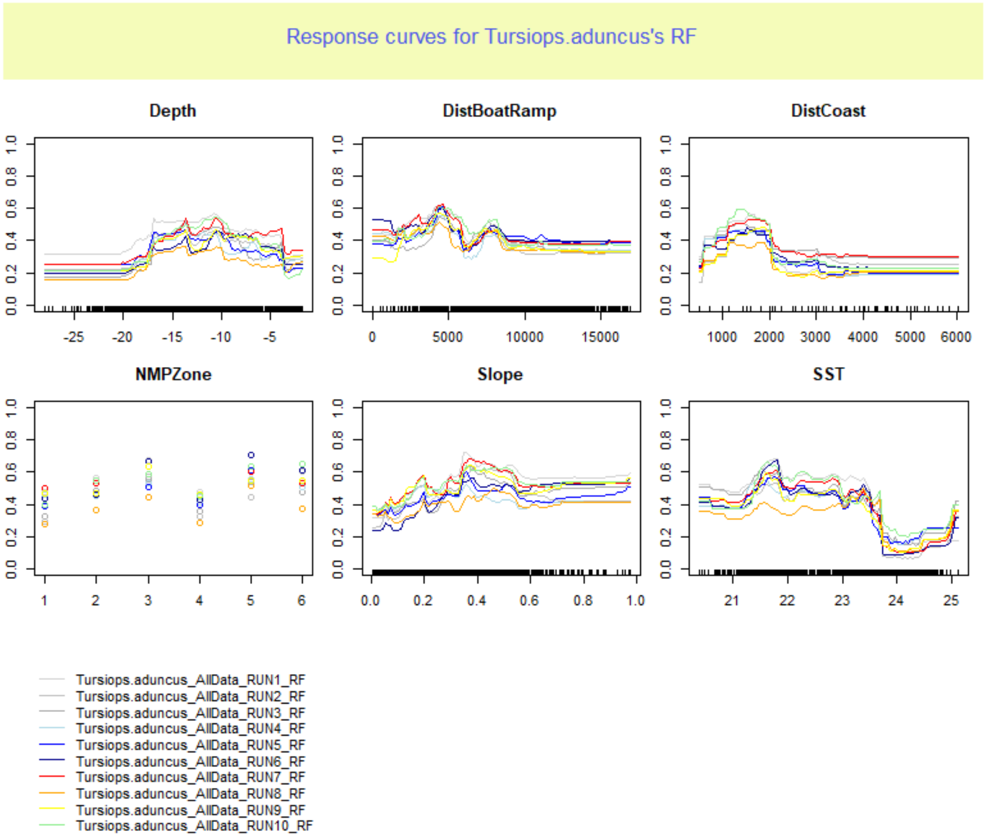
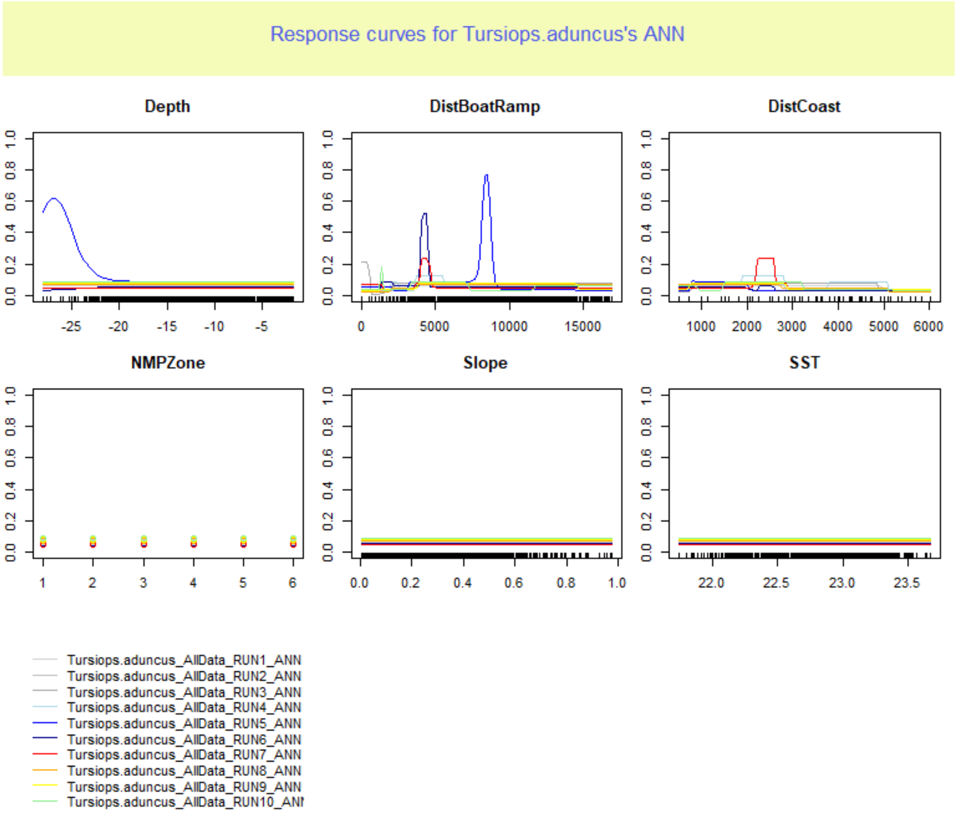
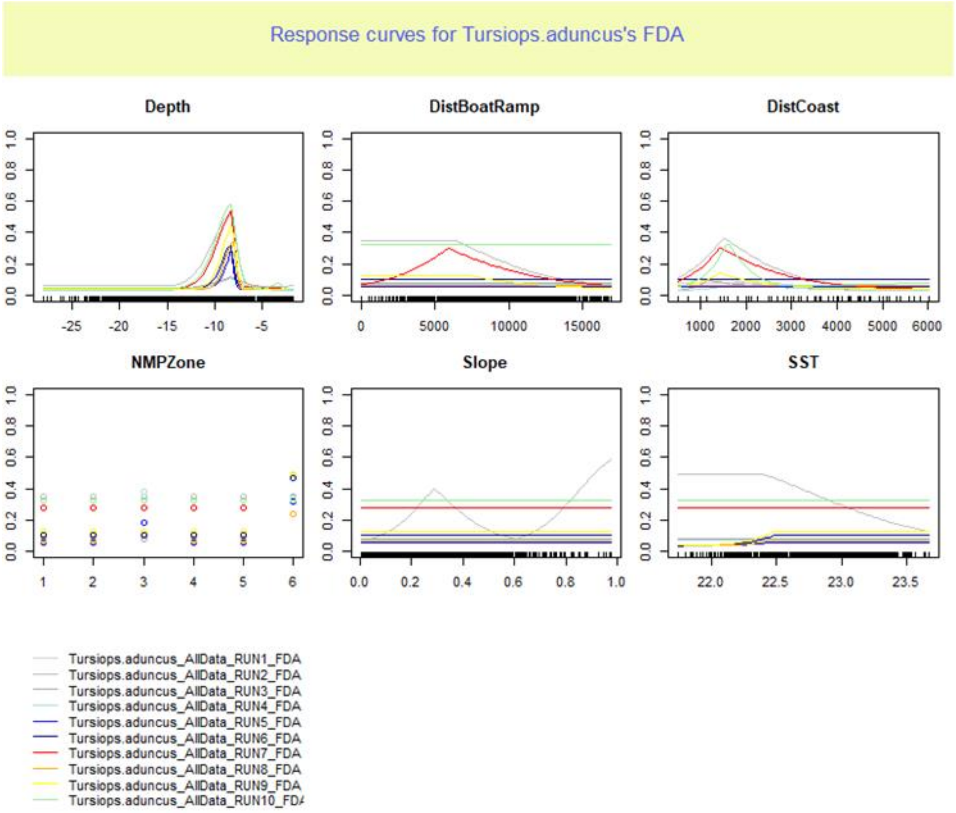
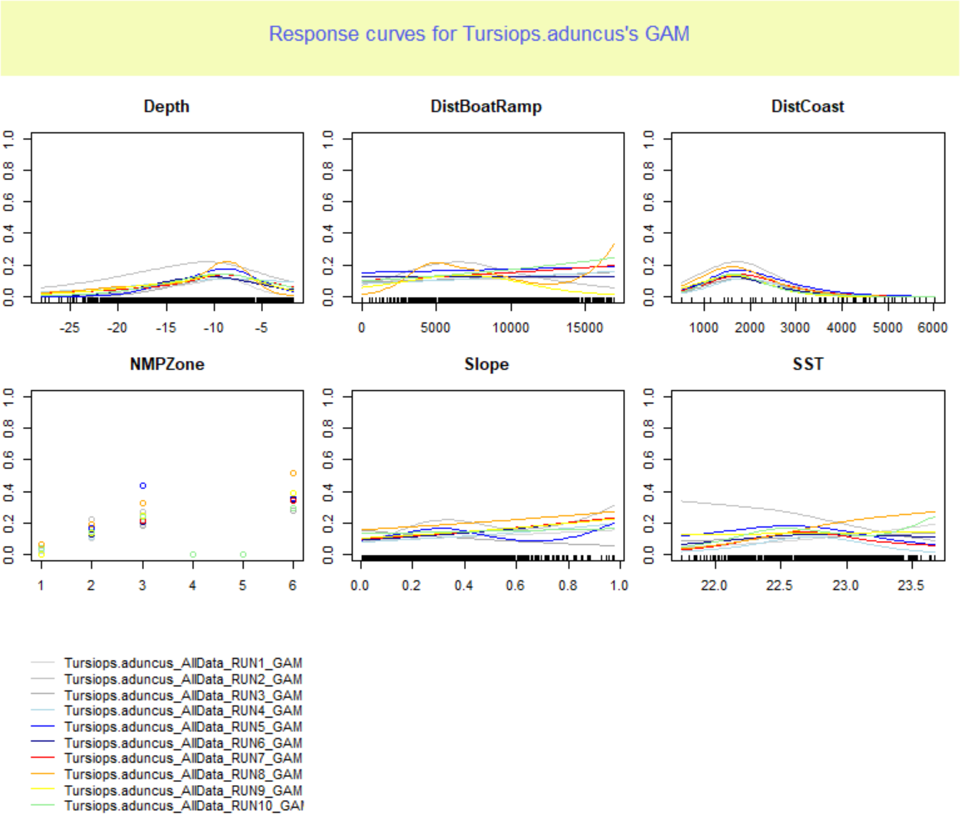


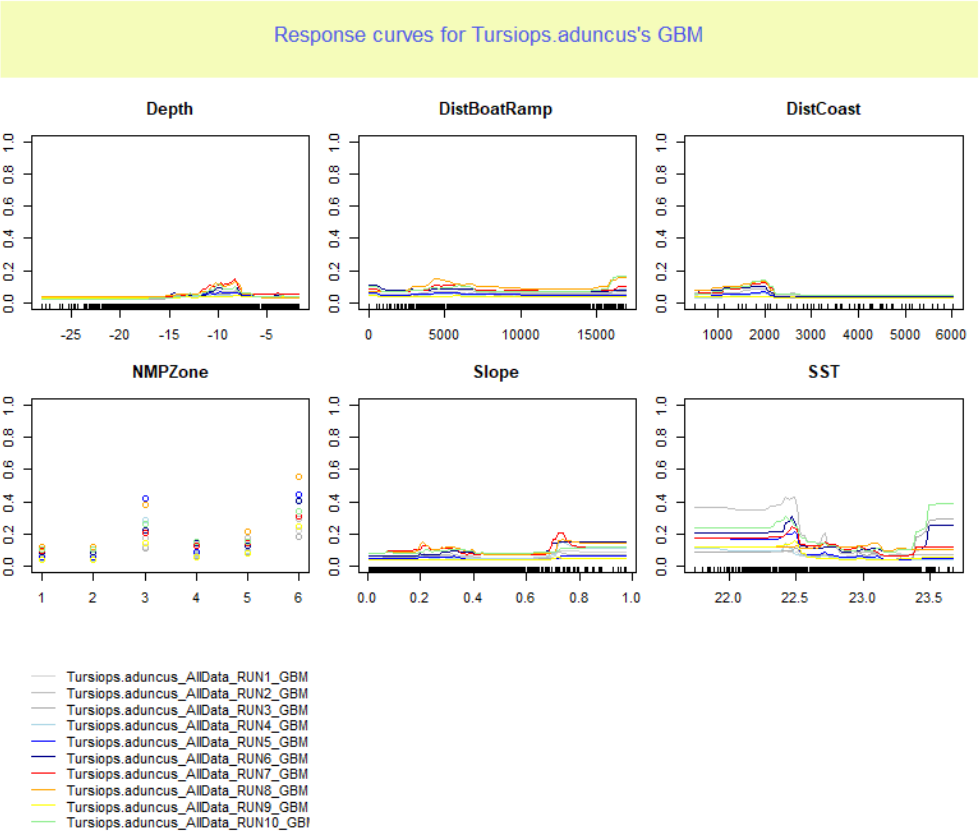
**Figure 8.13:** Response curves of the seven modelling algorithms used in the ensemble to model winter Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

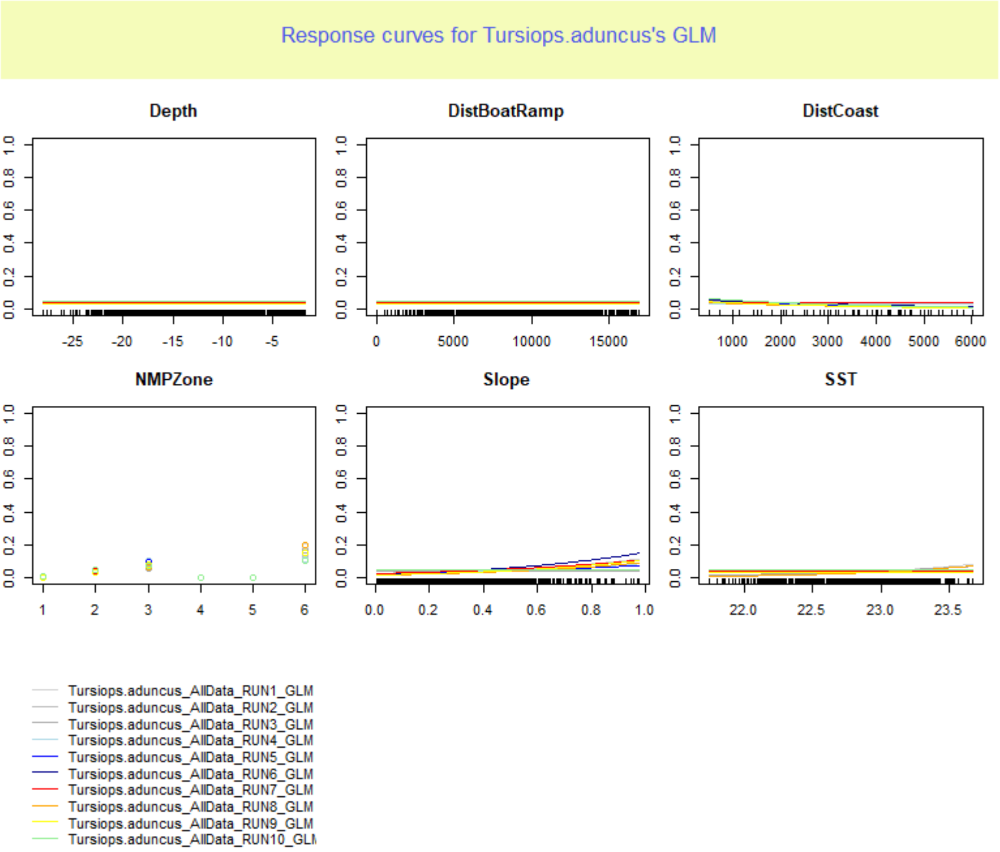
### *S2.6.3 Spring response curves (entire study area)*



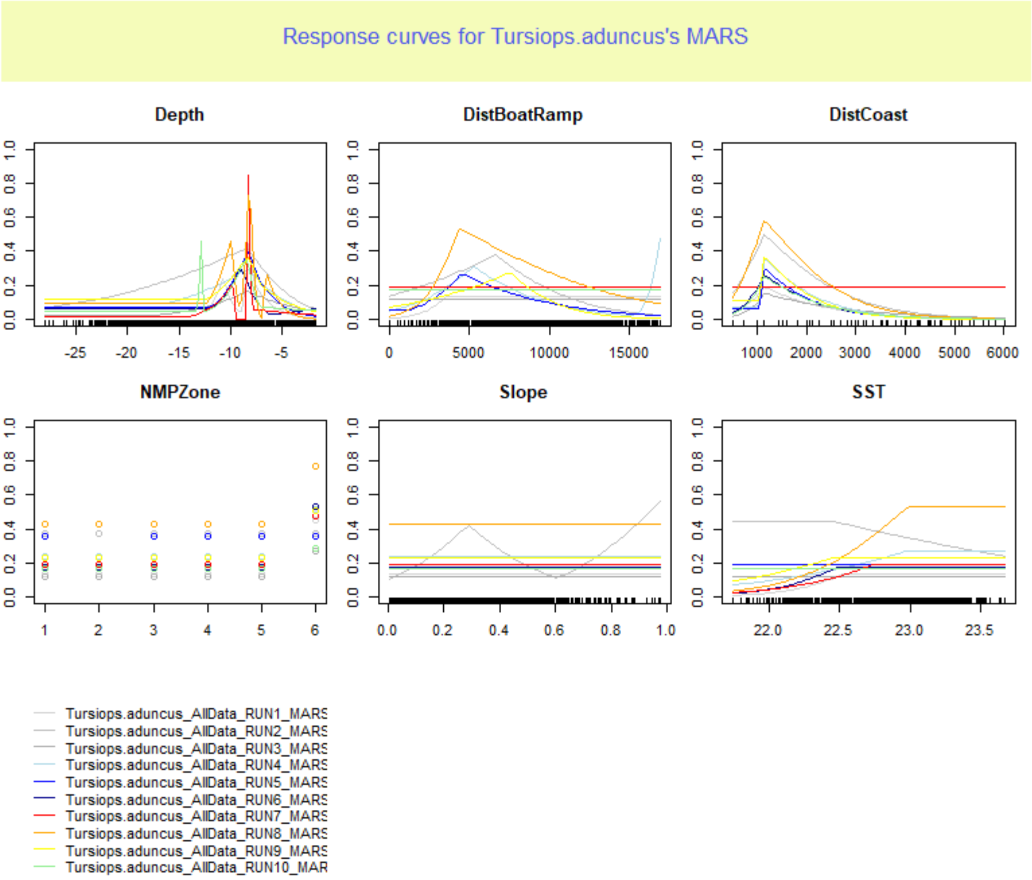



Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22.0 22.5 23.0 23.5
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GA


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22.0 22.5 23.0 23.5
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
Tursiops.aduncus_AllData_RUN9_GBM
Tursiops.aduncus_AllData_RUN10_GB



Response curves for Tursiops.aduncus's GLM



Response curves for Tursiops.aduncus's MARS

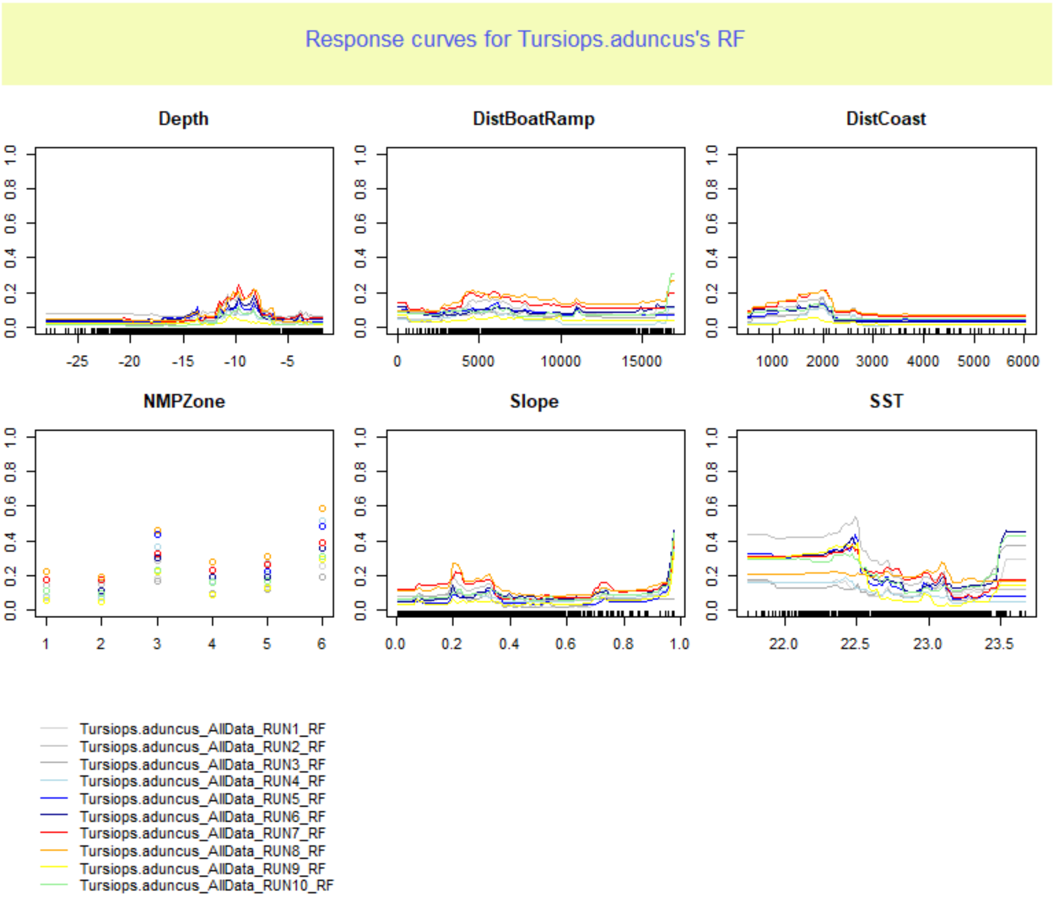


**Figure 8.14:** Response curves of the seven modelling algorithms used in the ensemble to model spring Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) distribution and habitat preferences at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model)

# 9 APPENDIX 3: SUPPORTING INFORMATION FOR CHAPTER 4

## S3.1: Habitat type definitions

Habitat type definitions used in the Ningaloo Marine Park behavioural species distribution models.

**Table 9.1:** Habitat type definitions used in the Ningaloo Marine Park species distribution models (obtained from DPaW. (2006)).

| Habitat Type | Definition |
|---|---|
| Bare reef (intertidal) | The bare reef (intertidal) habitat is located in the intertidal zone (between the LAT and HAT) and may be offshore or contiguous to the coast. This habitat includes low cliffs (<5 m high), high cliffs (>5 m high), boulders (>25.6 cm particle size), or pavement of igneous (granite/basalt), metamorphic (gneiss/schists), or sedimentary (limestone/sandstone) substratum. The bare reef (intertidal) is typically unvegetated but may have algal turfs present. This habitat may contain a variety of mollusc species including oysters (eg. *Saccostrea spp*.), abalone (eg. *Haliotis spp*.) nerites (eg. *Nerita spp. Nodolittorina spp., Littoraria spp*.), chitons (eg. *Ischnochiton spp*.) and barnacles (eg. *Tetraclita porosa*). Rock crabs (*F. Grapsidae*) also inhabit this habitat. |
| Bare reef (subtidal) | Bare reef (subtidal) is located in subtidal areas with either sedimentary (eg. limestone, sandstone), igneous (eg. granite, granophyre) or metamorphic (eg. schist, gneiss) substratum, either as pavement or boulder (>25 cm) fields. This habitat typically includes areas covered by mobile sand veneers, and is located in deep water offshore or in subtidal lagoonal areas. Bare reef (subtidal) habitats are typically bare but may have vegetation (eg. *Thalassodendron spp., Padina spp*.), or have sparse cover sessile invertebrates such as sponges (eg. *Cymbastella spp., Carteriospongia spp*.), octocorals, soft corals and ascidians. |
| Coral reef (intertidal) | The coral reef (intertidal) habitat is located in the intertidal or shallow regions (<1 m LAT) on a limestone substrate. This habitat includes the reef crest, shallow reef fronts, reef flats and shallow back reef zones (see Veron, 2000). Live coral cover varies greatly and some areas have a high proportion of coral rubble. Macroalgae, sand, reef rubble or pavement also may be present. Hard corals (eg. *Acropora spp*.) and soft corals (eg. *Sinularia spp*.) are typical of the fauna present in these habitats. Parts of this habitat typically support a high diversity and abundance of fish and invertebrate fauna. |

| Habitat Type | Definition |
|---|---|
| Coral reef (subtidal) | The coral reef (subtidal) habitat is located in the subtidal zone and often has high live coral cover with macroalgal turf and coralline algae covering areas of reef not occupied by living corals. Sand patches, bare pavement and rubble may also be present. This habitat is used to describe the upper seaward reef slope, sheltered back reef, deep lagoonal reef (Veron, 2000) and bommie clusters. Typically, areas of high coral cover are generally restricted to water depths of less than 15 m depth. Offshore, the coral reef (subtidal) habitats are dominated by the faster growing coral species such as Acropora (eg. *A. hyacinthus*) and Pocillopora (eg. *P. verrucosa*). This habitat typically supports a high diversity and abundance of fish and other coral reef fauna such as crabs (Families Xanthidae and Portunidae) and snapping shrimp (*Alpheus spp*.). |
| Macroalgae | The macroalgae (subtidal) habitat is subtidal areas with sedimentary, igneous or metamorphic substratum of low or high relief. This habitat is found in deep and shallow-waters and also may incorporate mobile sand patches, and scattered isolated hard and soft corals. This habitat generally is covered in large fleshy macroalgae (eg. *Sargassum spp., Cystophora spp., Ecklonia spp*.) or macroalgal turf (thallus height <100mm) comprised of red (eg. *Laurencia spp*.), green (eg. *Enteromorpha spp., Ulva spp. Caulerpa spp*.) and brown (eg. *Padina spp., Turbinaria spp*.) algae. A wide range of invertebrate life such as sponges, ascidians, gastropods, seastars, brittle stars, sea urchins and soft corals, are associated with this habitat. Crustaceans such as the western rock lobster (*Panulirus cygnus*), painted rock lobster (*P. vericolor*), ornate rock lobster (*P. ornatus*) and the southern rock lobster (*Janus edwardsii*) are often found in macroalgae (subtidal) habitats. |
| Mangroves | The mangrove habitat describes areas of mangrove forest greater than 0.05 ha and typically is located in the upper intertidal zone. The substratum of this habitat is typically comprised of mud and silt; however some mangrove species do occur on intertidal rocky shores. In Western Australia, the most common mangrove species are *Rhizophora stylosa* and *Avicennia marina*, the latter occurring as far south as Bunbury. Mangrove roots provide a substratum for many gastropods (eg. *Natica sp., Cerithium sp., Strombus spp*.) and other invertebrates, such as the mangrove crab (*Scylla serrata and Scylla olivacea*) and fiddler crab (*Uca sp*.)are often present. Mangals are an important habitat for birds such as the mangrove whistler (*Pachycephala melanura*) and brahminy kite (*Haliastur indus*). |
| Mobile sand | The mobile sand (subtidal) habitat is defined as subtidal habitats that have predominantly white carbonate sands (0.1-2 mm grain size) as a substrate, which is constantly being moved by currents or wave action. However, the sand may overlay reef platform or have patches of other |

| **Habitat Type** | **Definition** |
|---|---|
| | habitats present. Mobile sand (subtidal) habitats typically are bare, and may have seasonal vegetation or permanent patches of seagrass or macroalgae. Invertebrate infauna such as scallops (eg. *Pecten spp*.) seastars (eg. *Astropecten spp*.), and sea urchins (eg. *Brissus spp., Echinocardium spp*.), may also be present. |
| Pelagic | The pelagic habitat is defined as habitats with greater than 50 m depth. The pelagic habitat is dominated by the life in the water column, which include pelagic fish, pelagic invertebrates, zooplankton and phytoplankton. Contemporary acoustic mapping techniques have been able to discern hardness (soft and hard) and relief (smooth and rough) which may be used for local scale habitat mapping (Penrose & Siwabessy, 2001; Siwabessy et al., 1999). |
| Saltmarsh | The saltmarsh habitat describes areas of low relief located in the upper intertidal zone of low energy coastlines. The substratum consists of muddy or silty terrigenous sediment. Saltmarsh habitats often occur landward of mangals, tidal creeks and estuaries, and typically supports vegetation such as the saltwater couch (*Sporobolus virginicus*) and blue-green algal mats (eg. *Microcoleus chthonoplastes, Oscillotoria sp., Phoridium sp*.), but can also occur as unvegetated coastal saline flats. In the tropics, burrowing crabs (*Uca sp*.), soldier crabs (*Mictyris sp*.) and *Cerinthium spp.* gastropods are conspicuous fauna in this habitat. In temperate areas, the glassswort *Sarcocornia quinqueflora* and *Sporobolus virginicus* are conspicuous flora in this habitat. |

## S3.2: Ningaloo Marine Park SDMs to assess the influence of benthic habitat type models

### *S3.2.1 Foraging*

Most of the single foraging behaviour SDMs performed well, with moderate to good AUC values (AUC values ranged from 0.42– 0.83; median = 0.72, Figure 9.1), with the exception of several runs from the ANN algorithm. The foraging ensemble model outperformed all single SDMs with an AUC of 0.96, indicating excellent model performance (Figure 9.1).

The Ningaloo Marine Park (NMP) ensemble models detailing the probability of occurrence of IP bottlenose dolphins engaging in foraging behaviours in the coastal waters of the NWC within the NMP revealed core areas where this behavioural state was more likely to occur. When modelling all foraging data, this behaviour was found to be mostly linked to distance to boat ramp (0.47) and distance to coast (0.36) (Table 9.2). Response curves indicated that foraging behaviours were more likely to occur up to 5000 m from the nearest boat ramp and 1000 – 2000 m from the coast (see S3.6, Figure 9.6).

Within the NMP, foraging was modelled with a high probability of occurrence (>0.81) in recreational zone waters of VLF Bay and the Bundegi area (Figure 9.2). Moderate probability of occurrence (0.61-0.80) was modelled from VLF Bay to the south-eastern boundary of the NMP.

**Table 9.2:** Importance of environmental and anthropogenic variables for the single and ensemble species distribution models of foraging Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) within the Ningaloo Marine Park (NMP) at the North West Cape (NWC), Western Australia (WA). Seven model algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA) (Hastie et al. 1994), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as an ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| **Foraging (NMP Dataset)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Model** | **Explanatory variables** | | | | | | |
| | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** | **Habitat** |
| ANN$^{0}$ | **0.85** | 0.65 | 0.01 | 0.00 | 0.01 | 0.21 | 0.01 |
| FDA$^{3}$ | 0.35 | 0.24 | 0.40 | **0.41** | 0.01 | 0.17 | 0.00 |
| GAM$^{8}$ | 0.34 | **0.43** | 0.35 | 0.22 | 0.05 | 0.10 | 0.38 |
| GBM$^{7}$ | **0.47** | 0.19 | 0.03 | 0.25 | 0.18 | 0.04 | 0.17 |
| GLM$^{7}$ | **0.60** | 0.15 | 0.31 | 0.14 | 0.00 | 0.07 | 0.06 |
| MARS$^{4}$ | **0.45** | 0.44 | 0.09 | 0.39 | 0.02 | 0.08 | 0.00 |
| RF$^{7}$ | **0.26** | 0.13 | 0.04 | 0.15 | 0.19 | 0.07 | 0.12 |
| Mean of means | **0.47** | **0.32** | 0.18 | 0.22 | 0.07 | 0.11 | 0.11 |
| Ensemble | **0.47** | **0.36** | 0.20 | 0.19 | 0.07 | 0.13 | 0.12 |

### *S3.2.2 Resting*

Most of the single resting behaviour SDMs performed well, with moderate to good AUC values (AUC values ranged from 0.49– 0.85; median = 0.70), with the exception of several runs from the ANN algorithm. The resting ensemble model outperformed all single SDMs with an AUC of 0.96, indicating excellent model performance (Figure 9.1).

The NMP ensemble models detailing the probability of occurrence of IP bottlenose dolphins engaging in resting behaviours in the coastal waters of the NWC within the

NMP revealed core areas where this behavioural state was more likely to occur. When modelling all resting data, this behaviour was found to be mostly linked to marine park zone (0.46) and water depth (0.21) (Table 9.3). Response curves indicated that resting behaviours were more likely to occur in designated Sanctuary Zones (zone 3) and in water depths of 5 – 10 m (see S3.6 and Figure 9.7 in this Appendix).

High and moderate probability of occurrence for resting behaviour within the NMP fell exclusively within designated Sanctuary Zones. High probability (>0.81) was modelled in Jurabi and Lighthouse Bay Sanctuary Zones and moderate probability (0.61-0.80) was modelling in Mangrove Bay, Jurabi, Lighthouse Bay and Bundegi Reef Sanctuary Zones (Figure 9.2)

**Table 9.3:** Importance of environmental and anthropogenic variables for the single and ensemble species distribution models of resting Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) within the Ningaloo Marine Park (NMP) at the North West Cape (NWC), Western Australia (WA). Seven model algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA) (Hastie et al. 1994), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as an ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| **Resting (NMP Dataset)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Model** | **Explanatory variables** | | | | | | |
| | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** | **Habitat** |
| ANN$^{1}$ | **0.68** | 0.77 | 0.00 | 0.00 | 0.01 | 0.09 | 0.01 |
| FDA$^{6}$ | 0.00 | 0.01 | 0.47 | 0.24 | 0.08 | **0.57** | 0.06 |
| GAM$^{9}$ | 0.02 | 0.18 | **0.47** | 0.31 | 0.10 | 0.21 | 0.43 |
| GBM$^{9}$ | 0.10 | 0.11 | 0.27 | **0.30** | 0.10 | 0.17 | 0.22 |
| GLM$^{7}$ | 0.02 | 0.23 | **0.58** | 0.17 | 0.08 | 0.03 | 0.13 |
| MARS$^{7}$ | 0.01 | 0.17 | 0.28 | 0.17 | 0.07 | **0.55** | 0.05 |
| RF$^{8}$ | 0.09 | 0.10 | 0.14 | **0.22** | 0.08 | 0.13 | 0.12 |
| Mean of means | 0.13 | 0.22 | **0.32** | 0.20 | 0.07 | **0.25** | 0.15 |
| Ensemble | 0.05 | 0.15 | **0.46** | 0.20 | 0.07 | **0.21** | 0.17 |

### *S3.2.3 Travelling*

Most single SDMs performed well with moderate to good AUC values (AUC values ranged from 0.47 – 0.84, median = 0.75, Figure 9.1). The ensemble model outperformed all single SDMS for dolphin travelling behaviour with an AUC of 0.95 (Figure 9.1).

The ensemble models detailing probability of occurrence of IP bottlenose dolphins engaging in travelling behaviours in the coastal waters of the NWC revealed a high concentration of travelling around the tip of the NWC. Modelling travelling data revealed this behaviour was mostly linked to distance to coast and seabed slope (Table 9.4). Response curves indicated that travelling was more likely to occur in waters 1000 – 2000 m from the coast and in slightly steeper slopes (see S3.6 and Figure 9.8 in this Appendix).

Ensemble models predicted the highest probability of occurrence (>0.81) of travelling behaviours within the NMP in the Recreational Zones adjacent to the Point Murat Sanctuary Zone. Moderate probability of occurrence (0.61 – 0.80) was continuously distributed from the Lighthouse Bay Santuary Zone to the boundary of south-eastern boundary of the NMP (Figure 9.2).

**Table 9.4:** Importance of environmental and anthropogenic variables for the single and ensemble species distribution models of travelling Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) within the Ningaloo Marine Park (NMP) at the North West Cape (NWC), Western Australia (WA). Seven model algorithms were used: artificial neural network (ANN), flexible discriminant analysis (FDA) (Hastie et al. 1994), generalised additive model (GAM), generalised boosted model (GBM), generalised linear model (GLM), multivariate adaptive regression splines (MARS) and random forest (RF). Variable importance is presented as the mean value over the 10 runs of each algorithm, the mean of means amongst them and as an ensemble value calculated using only the runs that met the AUC (area under the curve of the receiver operating characteristic) evaluation criteria of ≥0.7. The number of runs of each algorithm that was included in the ensemble is indicated in subscript. Variables of greatest influence are highlighted in bold.

| **Travelling (NMP Dataset)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Model** | **Explanatory variables** | | | | | | |
| | **Distance to boat ramp** | **Distance to coast** | **MP zone** | **Seabed slope** | **SST** | **Water depth** | **Habitat** |
| ANN$^{3}$ | **0.83** | 0.71 | 0.05 | 0.01 | 0.03 | 0.36 | 0.07 |
| FDA$^{7}$ | **0.41** | 0.17 | 0.07 | 0.28 | 0.32 | 0.27 | 0.04 |
| GAM$^{10}$ | 0.26 | 0.29 | 0.28 | 0.23 | 0.12 | 0.11 | **0.38** |
| GBM$^{10}$ | **0.34** | 0.13 | 0.04 | **0.34** | 0.19 | 0.09 | 0.04 |
| GLM$^{7}$ | **0.34** | 0.28 | 0.26 | 0.26 | 0.00 | 0.09 | 0.19 |
| MARS$^{8}$ | **0.40** | **0.40** | 0.06 | 0.18 | 0.14 | 0.21 | 0.06 |
| RF$^{10}$ | 0.20 | 0.13 | 0.04 | **0.22** | 0.18 | 0.11 | 0.05 |
| Mean of means | **0.40** | **0.30** | 0.11 | 0.22 | 0.14 | 0.18 | 0.12 |
| Ensemble | 0.28 | **0.29** | 0.22 | **0.30** | 0.00 | 0.07 | 0.27 |

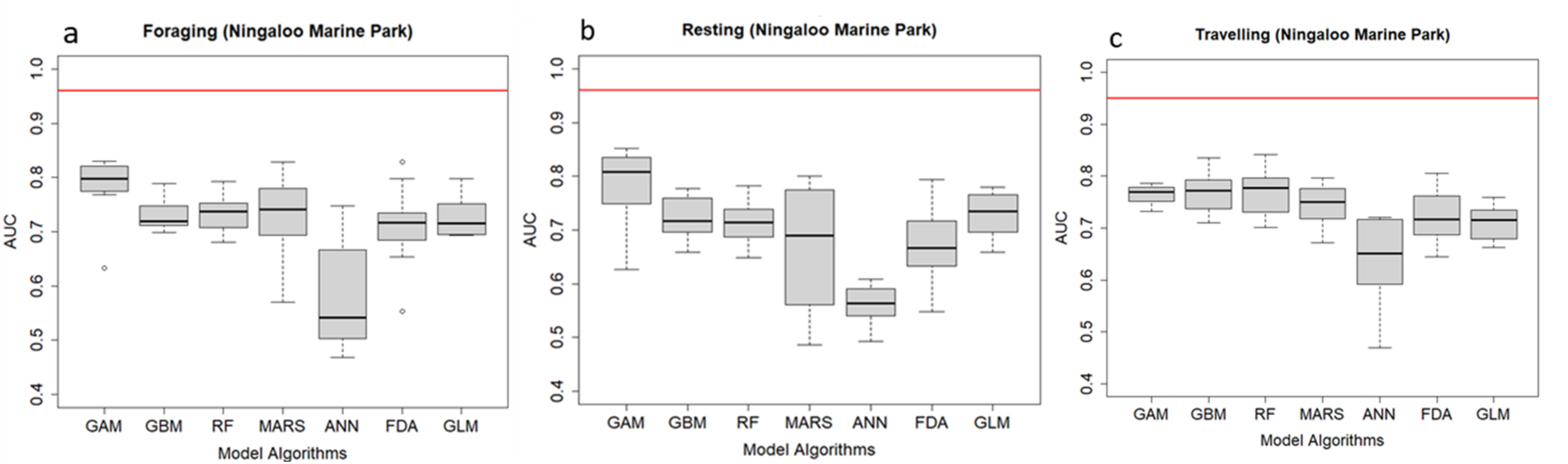


**Figure 9.1:** Performance of species distribution models of a) foraging, b) resting, and, c) travelling (*Tursiops aduncus*) within the Ningaloo Marine Park at the North West Cape, Western Australia. Boxplots for the AUC (area under the curve of the receiver operating characteristic) of the 10-cross validation runs of each modelling algorithm (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis, and GLM: generalised linear model). The red line shows the AUC of the ensemble model. Values of AUC ≥0.7 indicates that the model predictive performance is moderate to excellent.

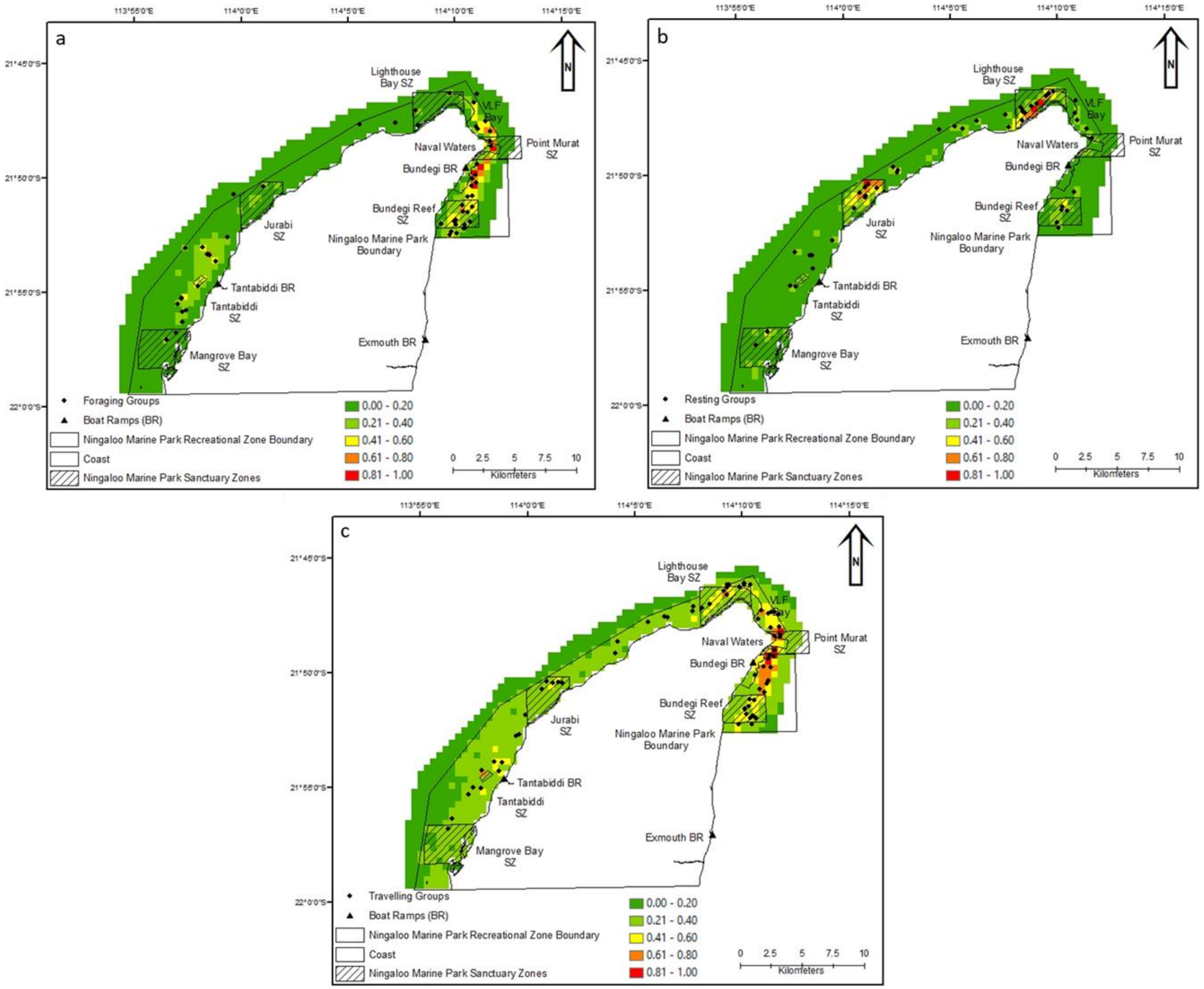


**Figure 9.2:** Ensemble models of the distribution of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) engaged in a) foraging, b) resting and, c) travelling within the Ningaloo Marine Park at the North West Cape, Western Australia. Colours as shown in the legend indicate the probability of occurrence 0.00 – 0.40 = low, 0.41 – 0.80 = moderate and 0.81 – 1.00 = high. The Ningaloo Marine Park boundary, recreational, sanctuary zones and boat ramps are marked on the map. Outside the recreational zone boundary is the General Use zone and the unmarked part of the Point Murat Sanctuary zone is the area classified as Naval Waters.

## S3.3: Biomod2 default model settings

ANN = NbCV = 5, size = NULL,decay = NULL, rang = 0.1, maxit = 200

FDA = method = 'mars', add_args = NULL

GAM = algo = 'GAM_mgcv',type = 's_smoother', k = -1, interaction.level = 0, myFormula = NULL, family = binomial(link = 'logit'), method = 'GCV.Cp',optimizer = c('outer','newton'), select = FALSE, knots = NULL,paraPen = NULL, control = list(nthreads = 1, irls.reg = 0, epsilon = 1e-07, maxit = 200, trace = FALSE, mgcv.tol = 1e-07, mgcv.half = 15, rank.tol = 1.49011611938477e-08, nlm = list(ndigit=7, gradtol=1e-06, stepmax=2, steptol=1e-04, iterlim=200, check.analyticals=0), optim = list(factr=1e+07), newton = list(conv.tol=1e-06, maxNstep=5, maxSstep=2, maxHalf=30, use.svd=0), outerPIsteps = 0, idLinksBases = TRUE, scalePenalty = TRUE, efs.lspmax = 15, efs.tol = 0.1, keepData = FALSE, scale.est = fletcher, edge.correct = FALSE)

GBM = distribution = 'bernoulli',n.trees = 2500,interaction.depth = 7,n.minobsinnode = 5,shrinkage = 0.001,bag.fraction = 0.5,train.fraction = 1,cv.folds = 3,keep.data = FALSE,verbose = FALSE, perf.method = 'cv',n.cores = 1)

GLM = type = 'quadratic',interaction.level = 0, myFormula = NULL,test = 'AIC', family = binomial(link = 'logit'), mustart = 0.5, control = glm.control(epsilon = 1e-08, maxit = 50, trace = FALSE) )

MARS = type = 'simple', interaction.level = 0, myFormula = NULL, nk = NULL, penalty = 2, thresh = 0.001, nprune = NULL, pmethod = 'backward')

RF = do.classif = TRUE, ntree = 500, mtry = 'default', nodesize = 5, maxnodes = NULL)

## S3.4: ODMAP checklist

– ODMAP Protocol –

*Overview*

*Authorship*

Behavioural processes underlying habitat selection of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the Ningaloo Marine Park and Exmouth Gulf, Western Australia.

Contact : rebecca.haughey@flinders.edu.au

*Model objective*

Model objective: Mapping and interpolation

Target output: To identify the functional use of habitats and relationship between important biological behaviours and anthropogenic and environmental conditions for Indo-Pacific bottlenose dolphins at the North West Cape.

*Focal Taxon*

Focal Taxon: Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)

*Location*

Location: North West Cape, Western Australia

*Scale of Analysis*

Spatial extent:

Universal Transverse Mercator zone 50 south based on the WGS 1984 datum

Top: 7591027.338288 m

Left: 17672.044127 m

Right: 211672.044127 m

Bottom: 7565027.338288 m

Spatial resolution: 500m by 500m

Temporal extent: 5 years (2013, 2014, 2015, 2018 & 2019)

Boundary: Rectangle

*Biodiversity data*

Observation type: Field survey

Response data type: Presence/absence of behavioural states

*Predictors*

Predictor types: Habitat, topographic and environmental

*Hypotheses*

Hypotheses: A number of environmental and anthropogenic variables have been shown to influence the distribution of cetaceans, in particular dolphins. I used measures of water depth, seabed slope, sea surface temperature, distance to coast, distance to the nearest boat ramp and marine park zone as predictor variables for the most frequently observed behavioural states displayed Indo-Pacific bottlenose dolphins. I also modelled the influence of benthic habitat type within the Ningaloo Marine Park.

*Assumptions*

Model assumptions: 1. Relevant ecological drivers of species distribution are included 2. Detectability does not change across transects 3. Species are at equilibrium with their environment 4. Sampling is adequate and representative (and any biases are accounted for/corrected)

*Algorithms*

Modelling techniques: glm, mars, ann, gam, fda, gbm, randomForest

Model averaging: We combined model algorithms to form an ensemble model/prediction.

*Workflow*

Only weakly correlated explanatory variables were included in the final models. Ensemble predictions were derived using means from model runs that performed well from the single model algorithms.

*Software*

Software: Analyses were conducted in R Studio using the biomod2 package (https://cran.r-project.org/web/packages/biomod2/index.html, https://github.com/biomodhub/biomod2). Additional packages required were raster, sp and rjava

ArcMap version 10.7 (ESRI) was used to create spatial layers of response (dolphin presence-absence) and predictor variables.

Code availability: Code is available on request

Data availability: Data are available on request

*Data*

*Biodiversity data*

Taxon names: Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)

Ecological level: Population/species

Data sources: Survey data was collected in the field over a 5 year period. Each field season (total = 5) was intensive and lasted 6 months, spanning over the austral seasons of autumn, winter and spring.

Sampling design: Boat based surveys searching for IP bottlenose dolphins were conducted onboard a 5.6 m vessel during the hours of 0700 and 1800 from May to

October in 2013, April to October in 2014, May to October in 2015 and April to September in both 2018 and 2019. Sampling periods spanned the Austral seasons of Autumn (March - May), Winter (June - August) and Spring (September – November). Surveys were conducted in favourable weather conditions (i.e. Beaufort Sea State of ≤3 and no rain) and followed a systematic line transect layout (2 x 93 km opposing zig zag lines and 1 x 13 km single line) covering a wide range of habitats, human use areas and environmental variables within the study area.

Sample size:

Over the five years of study, almost 723 hours of survey effort were completed. Survey effort varied slightly between years and austral seasons due to variability in weather conditions. Overall, the highest survey effort and number of dolphin sightings occurred, during the winter months (June-August). In total, 323 Indo-Pacific (IP) bottlenose dolphin schools were encountered: 111 travelling, 79 foraging, 53 resting, 29, socialising, 26 milling and 25 groups classified as unknown behaviour.

Clipping: All data covered the extent of the study area.

Scaling: 500m x 500m grid resolution.

Absence data: Each 500 m x 500 m grid within the survey area was assigned either a 1 (behavioural state presence) or 0 (behavioural state absence). In order to reduce false absences (i.e. determining an absent cell when individuals may in fact occur in that area), absence cells were defined based on areas which had the highest survey effort (Phillips et al. 2009). Survey effort was quantified using the total area of ‘on-effort’ survey tracks within each 500 x 500 m grid cell. A 250 m buffer area either side of each transect line was added, which was considered to be the average distance from the vessel that dolphins could reliably be observed under a variety of sea conditions (Zanardo et al 2017, Hunt 2018).Grid cells were then ranked and cells containing no dolphin presence and values of survey effort higher than the mean were considered most likely to represent true absences and therefore were defined as absence cells (Zanardo et al. 2017, Hunt 2018, Passadore et al. 2018).

*Data partitioning*

Training data: A random data splitting procedure of 75/25% was used for model calibration and testing. We implemented a 10-fold cross-validation method

Validation data: see training data

*Predictor variables*

Predictor variables: Predictor variables used to model distribution of the most frequent behavioural states engaged in by IP bottlenose dolphins were classified as: abiotic (i.e. water depth, slope, sea surface temperature (SST) and distance to coast), and anthropogenic (i.e. distance to boat ramp and marine park zone).

Data sources: Most data was collected in situ or calculated using the euclidean distance and cost distance tools in ArcMap. Marine park zoning data was obtained from the Western Australian Government's Department of Parks and Wildlife and is referenced in the paper

Spatial extent:

Top: 7591027.338288 m

Left: 17672.044127 m

Right: 211672.044127 m

Bottom: 7565027.338288 m

Spatial resolution: 500m x 500m

Coordinate reference system: All spatial layers were projected to Universal Transverse Mercator zone 50 south based on the WGS 1984 datum

Temporal extent: 6 month sampling periods repeated over 5 years (2013, 2014, 2015, 2018, 2019)

Temporal resolution: Entire study period (5 years combined)

Data processing: SST raster layers were created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size). Slope was calculated as the standard deviation of the depth and complexity as the standard deviation of the slope. Distance to the coast and boat ramps was measured using the Euclidean distance (i.e. shortest straight-line distance) and Cost distance (the shortest distance factoring in land given study area wraps around a peninsula) functions, respectively, using the Spatial Analyst extension in ArcMap. To evaluate the relevance of the marine park zoning for the conservation of IP bottlenose dolphins within the study area, a raster of marine park zones was created with the following zones; General, Recreational, Sanctuary, Special purpose, Naval waters and outside the NMP.

Errors and biases: Prey availability data is not known, but selected predictor variables have been used as proxies for prey availability/distribution.

*Transfer data*

ArcMap version 10.7 (ESRI) was used to create spatial layers of response (behavioural presence-absence) and predictor variables at a 500 x 500 m grid resolution (See *Methods: Response and Predictor variables* section in Chapter 4 of this thesis and Table S3.4 below). All spatial layers were projected to Universal Transverse Mercator zone 50 South.

**Table 9.5:** List of predictor variables used in species distribution modelling of Indo-Pacific bottlenose dolphins in the coastal waters of the North West Cape, Western Australia, their associated data source and how they were derived in ArcMap.

| Type of variable | Predictor variable | Variable abbreviation | Data Source |
|---|---|---|---|
| Abiotic | Distance to coast | N/A | Derived using the Euclidean distance tool (Spatial Analyst toolbox). |
| Abiotic | Slope | Slope | Derived using the Slope tool and is measured in decimal degrees (Spatial Analyst toolbox). |
| Abiotic | Sea surface temperature | SST | Derived from *in situ* measurements of SST. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size)(Spatial analyst toolbox). |
| Abiotic | Water depth | Depth | Derived from *in situ* measurements of depth. Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst toolbox). |
| Abiotic | Water visibility | N/A | Derived from *in situ* measurements of water visibility using a secchi disk and calculated as a proportion of the total depth.<br>Created using the Ordinary Kriging tool with a spherical semi variogram model (500m cell size, 12-point variable search radius size) (Spatial Analyst Toolbox). |
| Anthropogenic | Distance to boat ramp | N/A | Exmouth, Bundegi and Tantabiddi boat ramps are established vessel launch sites in the study area. Derived using the Cost distance tool (Spatial Analyst toolbox) and the coast shapefile as the cost surface. |
| Anthropogenic | Marine park zone | NMP Zone | A NMP zoning shape file which shows the zone boundaries was obtained from the Western Australian Government Department of |

|  |  |  |  |
|---|---|---|---|
|  |  |  | Biodiversity, Conservation and Attractions service. Each grid cell was assigned a variable according to MP zone using the polygon to raster tool (1=General Use, 2=Recreational, 3=Sanctuary, 4= Special Purpose, 5 = Naval Waters, 6 = outside the NMP) (DPaW. and DoF., 2014) |
| Biotic | Benthic habitat type | Habitat | Benthic habitat data only exists for the Ningaloo Marine Park portion of the study area (Figure 1). This data was derived from a broad scale benthic habitat study of the NMP (DPaW., 2006, Lucieer et al., 2017, Bancroft and Sheridan, 2000). Habitat type was classified as either 1=mobile sand, 2=mangroves, 3=bare reef (intertidal), 4=coral reef (intertidal), 5=bare reef (subtidal), 6=macro algae (subtidal), 7=coral reef (subtidal), 8=saltmarsh and 10=pelagic (No habitat type associated with a value of 9 (mudflat) is present in this section of the NMP). For habitat type definitions, see 3.1, Appendix 3. Each grid cell was assigned a variable according to habitat type using the polygon to raster tool. |

*Model*

*Multicollinearity*

Before running the SDM's, I tested for collinearity between our continuous numerical explanatory variables using stepwise procedures within the usdm package in RStudio (Naimi, 2015). Variance inflation factors (VIF) were calculated for all variables. Variable pairs with a maximum linear correlation greater than the threshold (0.7) were identified using 'vifcor' and the variable with the highest variance inflation factor (VIF, threshold = 3) was excluded using 'vifstep' (Zuur et al., 2010). These procedures were repeated until there was no variable remaining with a correlation coefficient greater than 0.7 and no variables with a VIF greater than the threshold (Naimi et al., 2014).

*Model settings*

See S3.3 in Appendix 3 for model settings.

*Model estimates*

The importance of explanatory variables was calculated using a 10-permutation run randomisation procedure within BioMod2 (Thuiller et al., 2009). This procedure allows for a direct comparison between model algorithms and calculates the Pearson's correlation between the standard predictions and predictions where 1 variable has been randomly permutated. High correlation (i.e. little difference between the two predictions) indicates that the variable is not important in the model, and a low correlation indicates that the variable is important. Variables are ranked from 0 to 1 according to the mean correlation coefficient, with the variable with the highest ranking the most influential and the lowest, the least influential (Thuiller et al., 2009).

### *Analysis and Correction of non-independence*

To ensure independence of data points in the face of bottlenose dolphins exhibiting flexible grouping patterns, termed fission fusion (Wells et al., 1987), only the locational point where the initial group members were first encountered whilst on transect and the predominant behaviour observed at the onset were included in analysis.

### *Threshold selection*

To compare modelling algorithms and for comparability with other studies, we used the AUC metric which has been standard and widely used in many SDM studies (Fielding and Bell, 1997). Values of AUC range from 0 to 1; with values >0.5 indicating that the model predictions perform better than random, whereas values <0.5 indicates that the model predictions are no better than what would be expected by chance. In general, AUC values of 0.5–0.7 are considered low and represent poor model performance, values of 0.7–0.9 are considered moderate to good, and values above 0.9 represent excellent model performance (Peterson et al., 2011).

### *Assessment*

### *Performance statistics*

Model performance was assessed based on AUC values using a threshold of 0.7. Final ensembles were generated using AUC values.

### *Plausibility check*

I referred to the response curves of each algorithm to examine the plausibility of the most important explanatory variables.

*Prediction*

*Prediction output*

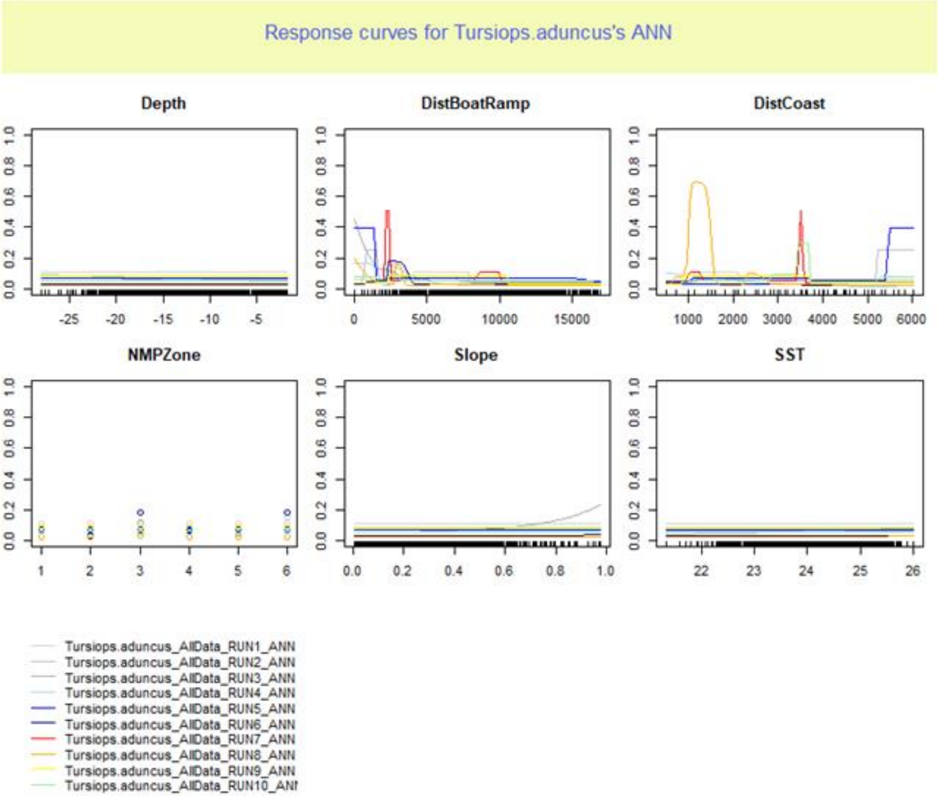
Prediction of probability of occurrence was expressed as 0.00 – 0.40 = low, 0.41 – 0.80 = moderate and 0.81 – 1.00 = high.

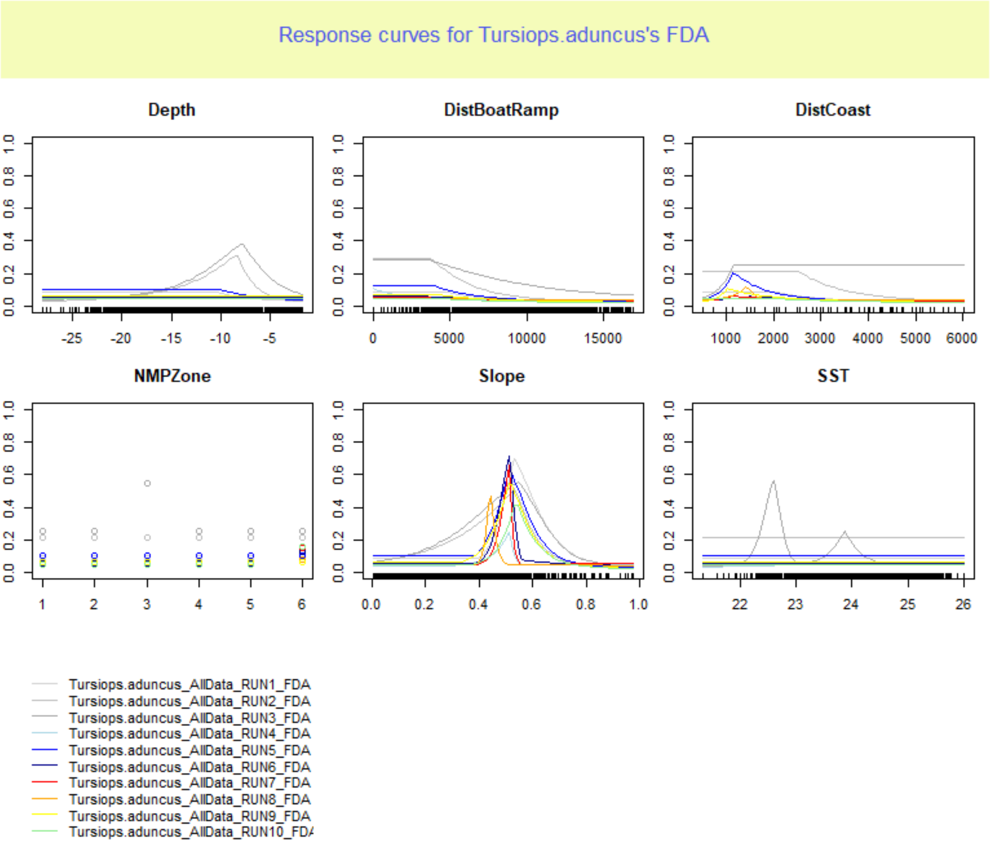
*Uncertainty quantification*

An ensemble approach was used combining all individual SDM algorithms that had performed well (≥0.7 AUC). The ensembles performed better than all single model algorithms and results from ensembles supported those of the individual algorithms and were able to overcome any discrepancies in most influential explanatory variable between single SDMs, although usually the single SDMs presented one of the top two variables presented by the ensemble.

## S3.5 Response curves for behavioural state species distribution models (entire study area)

### *S3.5.1 Foraging response curves (entire study area)*




Response curves for Tursiops.aduncus's FDA
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_FDA
Tursiops.aduncus_AllData_RUN2_FDA
Tursiops.aduncus_AllData_RUN3_FDA
Tursiops.aduncus_AllData_RUN4_FDA
Tursiops.aduncus_AllData_RUN5_FDA
Tursiops.aduncus_AllData_RUN6_FDA
Tursiops.aduncus_AllData_RUN7_FDA
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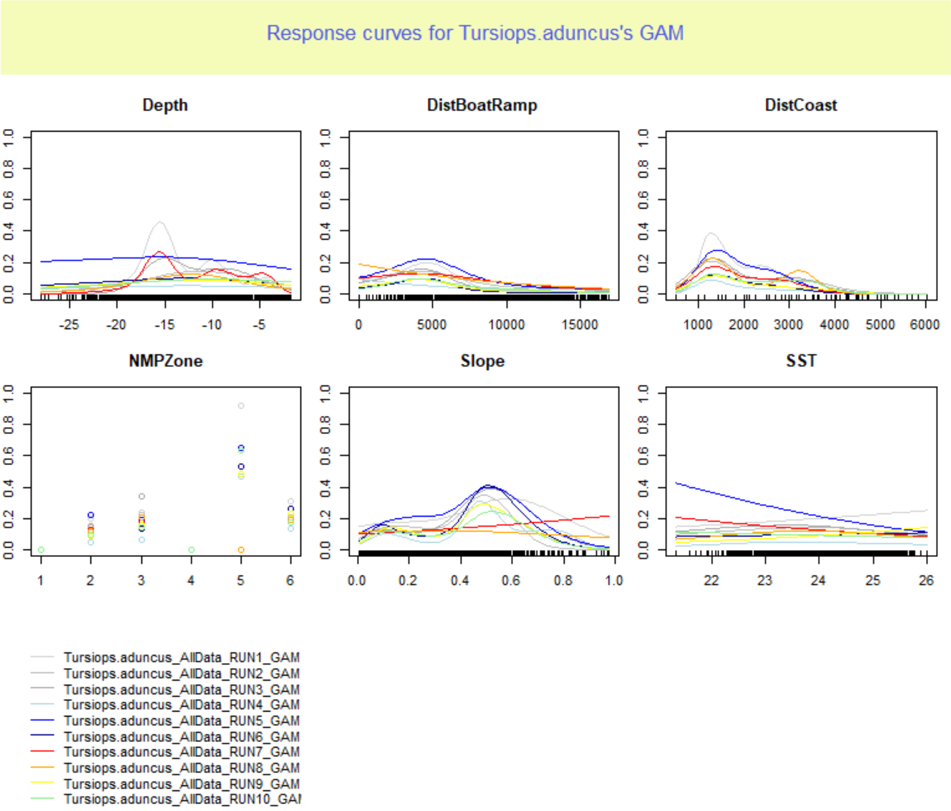
Tursiops.aduncus_AllData_RUN9_FDA
Tursiops.aduncus_AllData_RUN10_FD


Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
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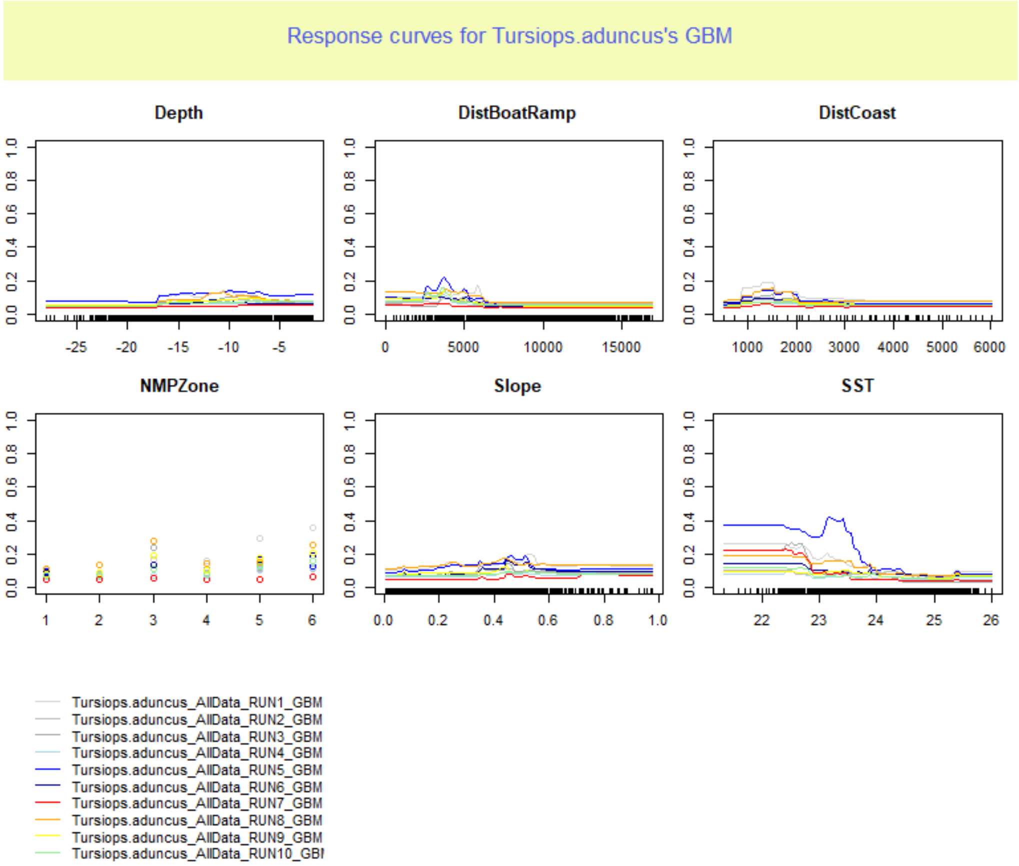
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GA


Response curves for Tursiops.aduncus's GBM
Depth
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DistCoast
NMPZone
Slope
SST
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0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
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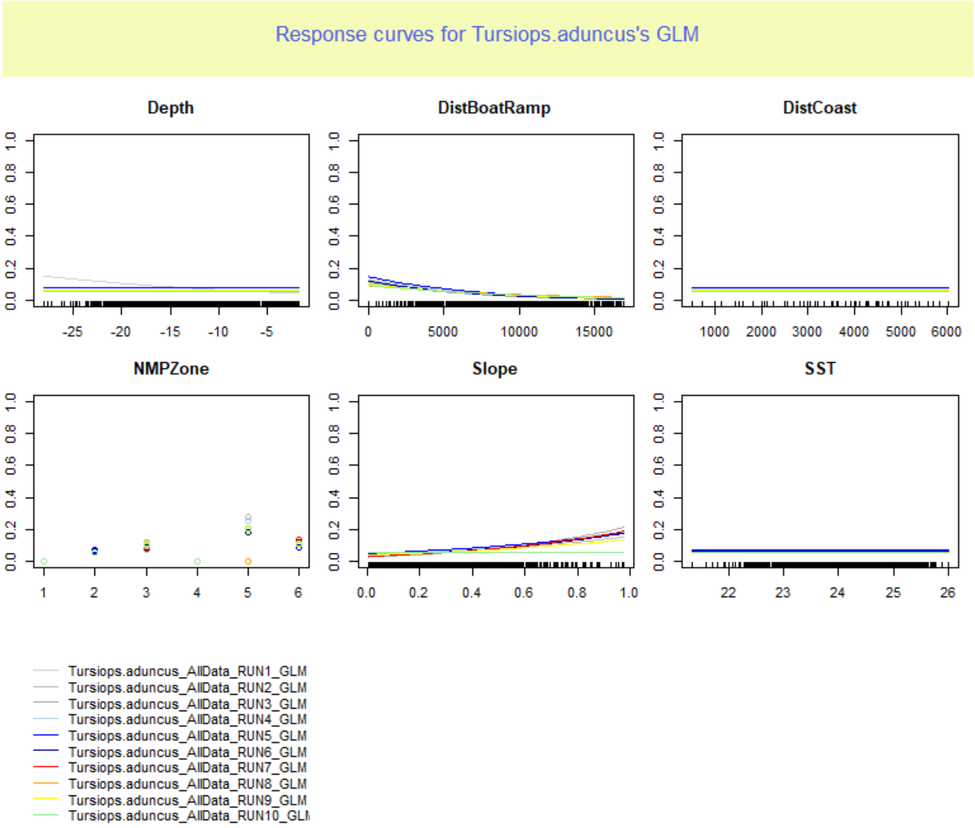
Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
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0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
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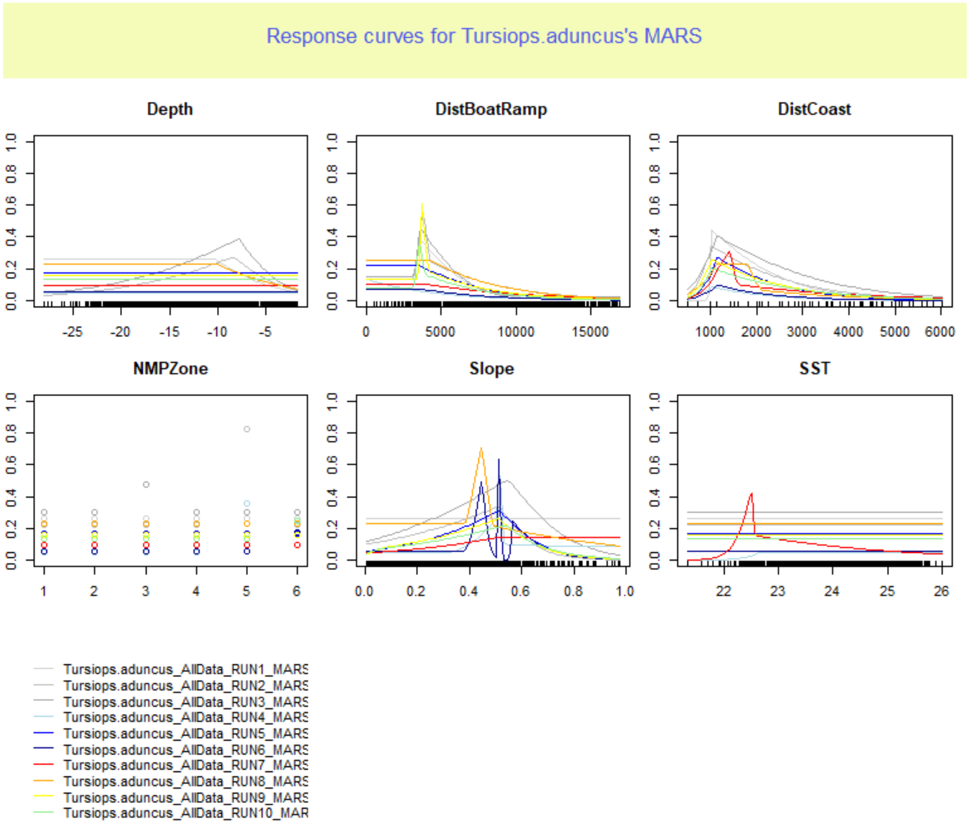
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GLI



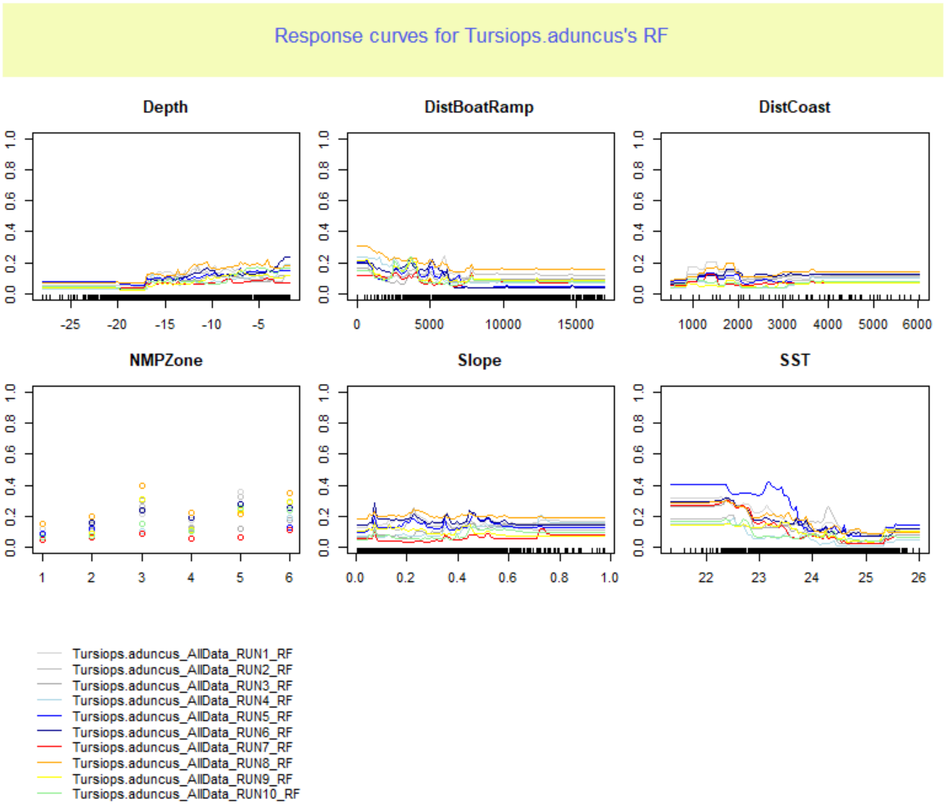
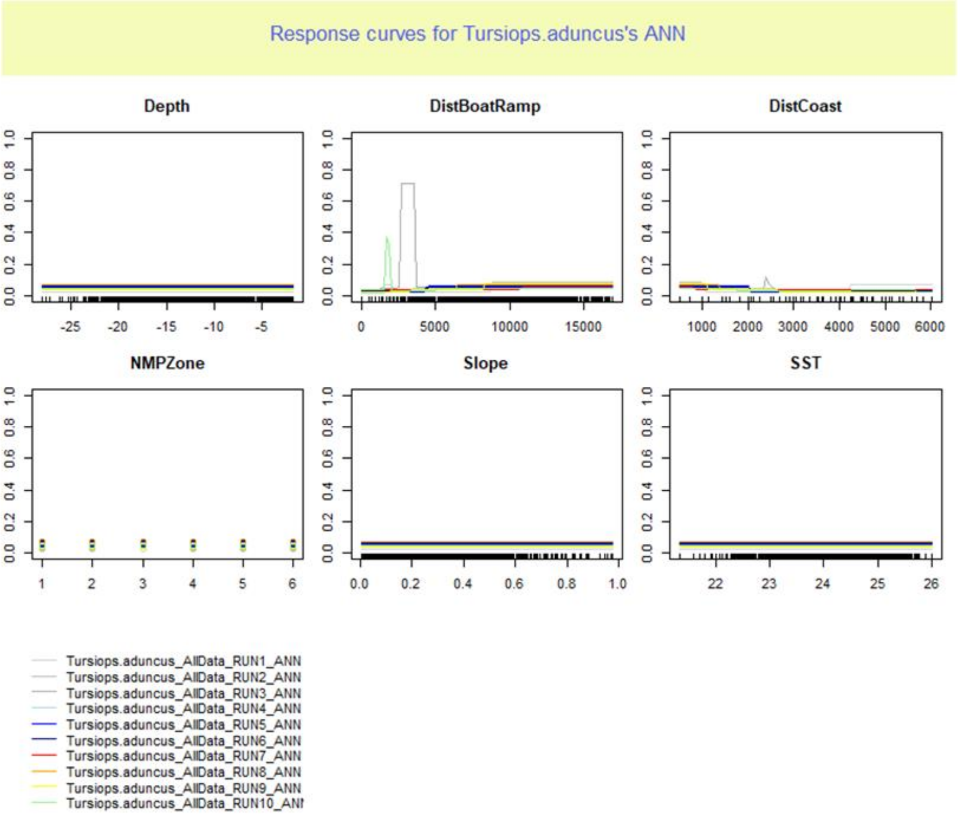
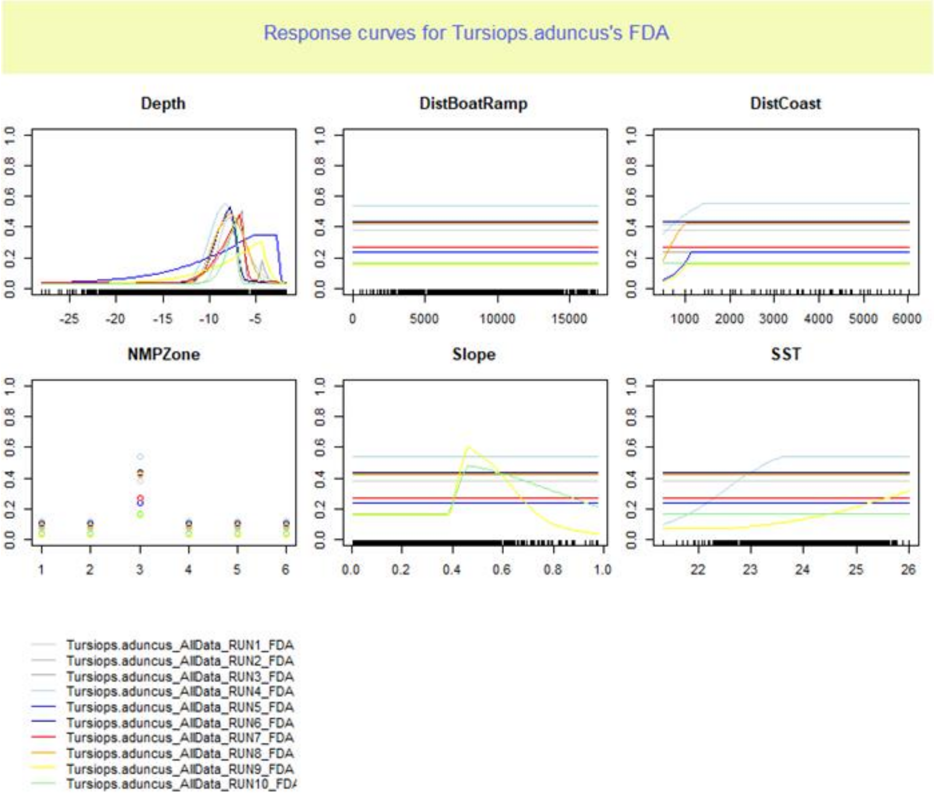


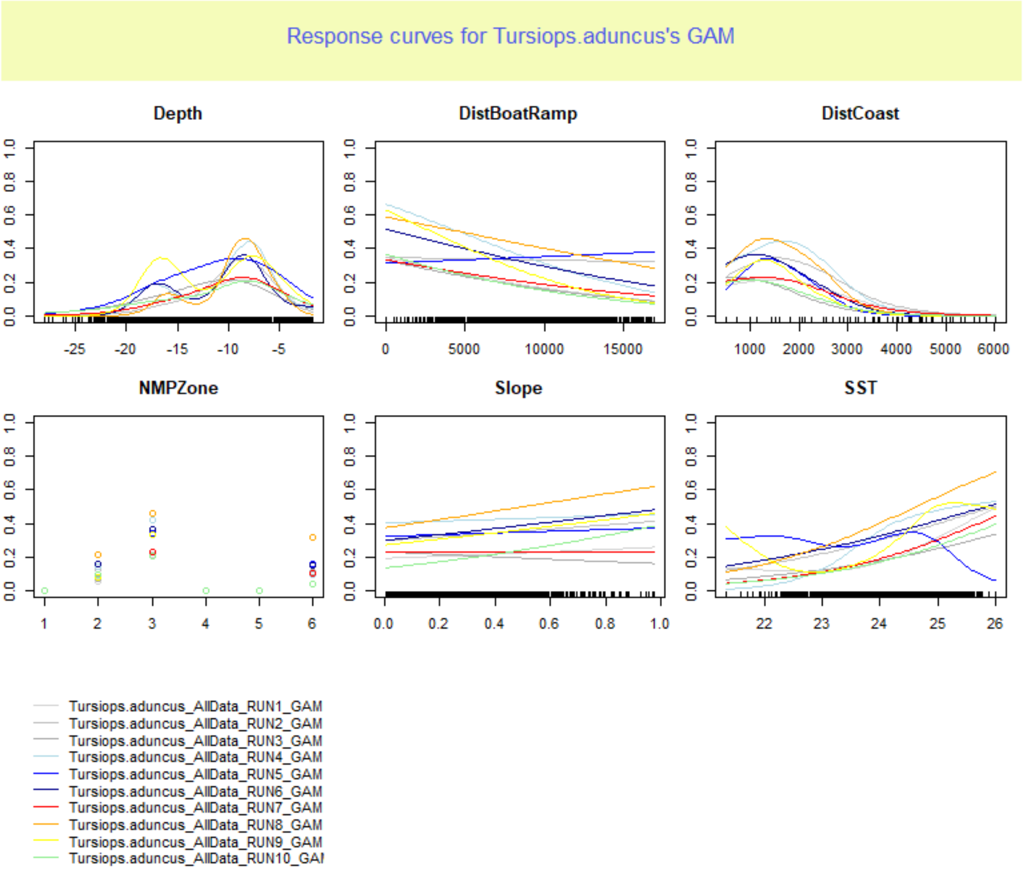
**Figure 9.3:** Response curves of the seven modelling algorithms used in the ensemble to model distribution and habitat preferences of foraging Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) groups at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate

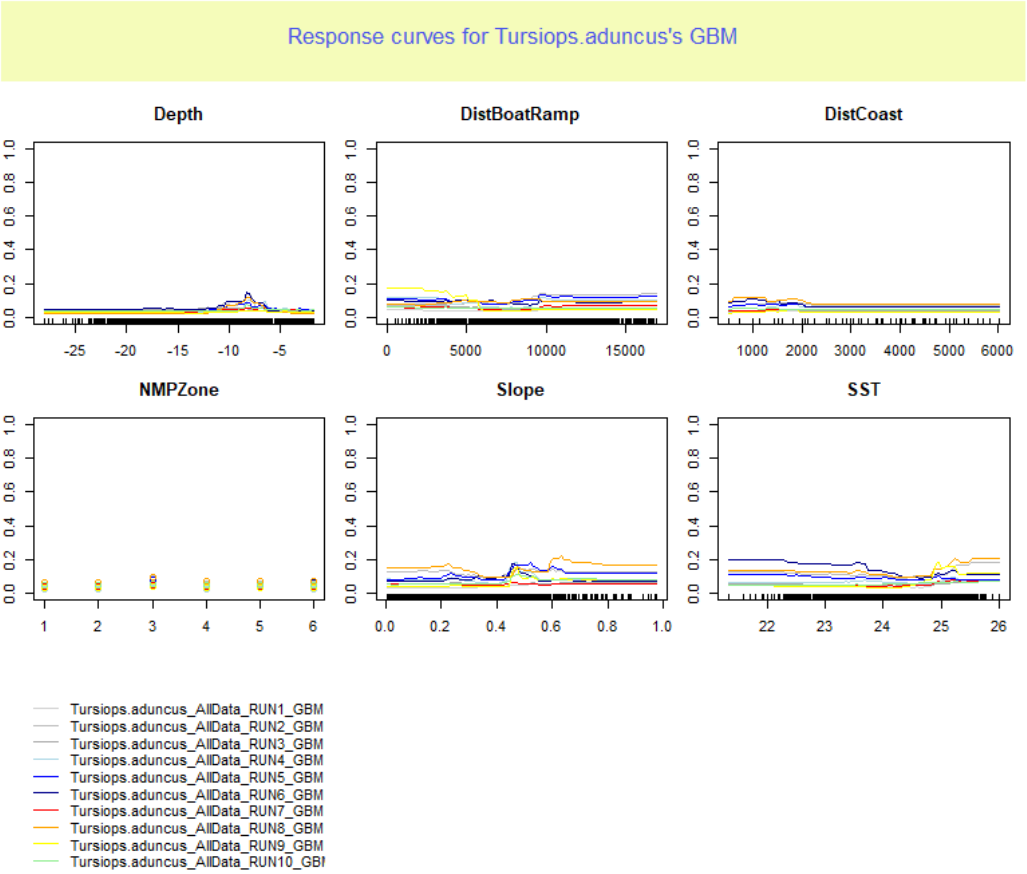
adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

### *S3.5.2 Resting response curves (entire study area)*






Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GA


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
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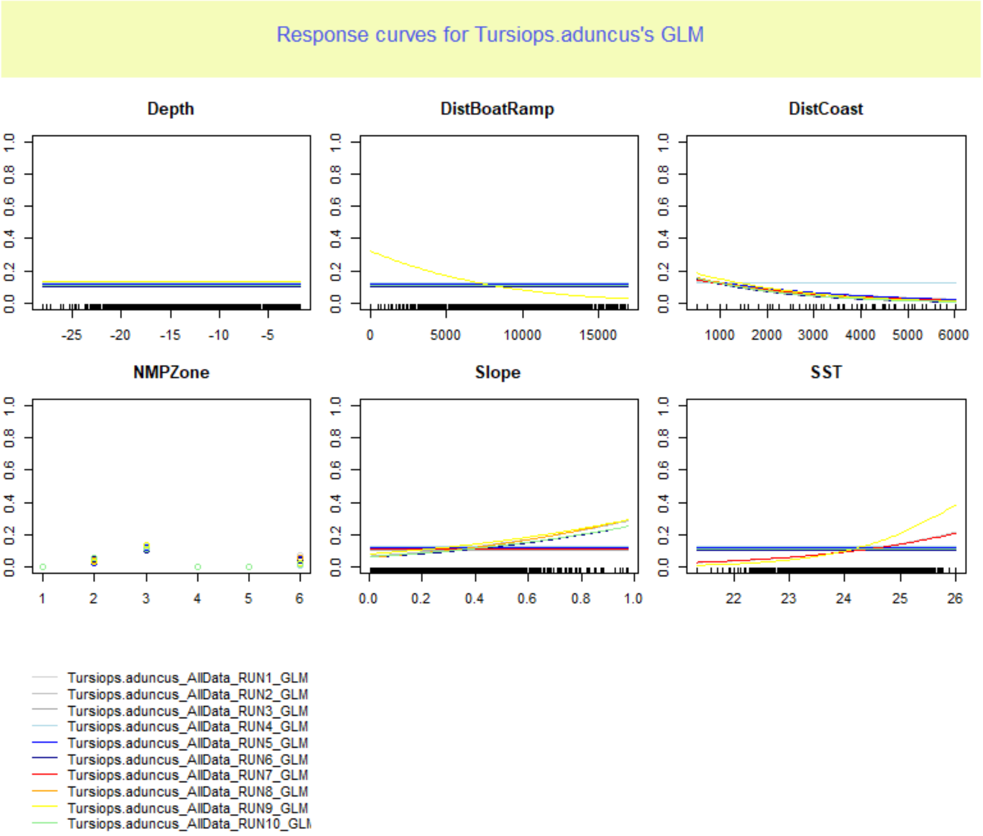
Tursiops.aduncus_AllData_RUN10_GB


Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
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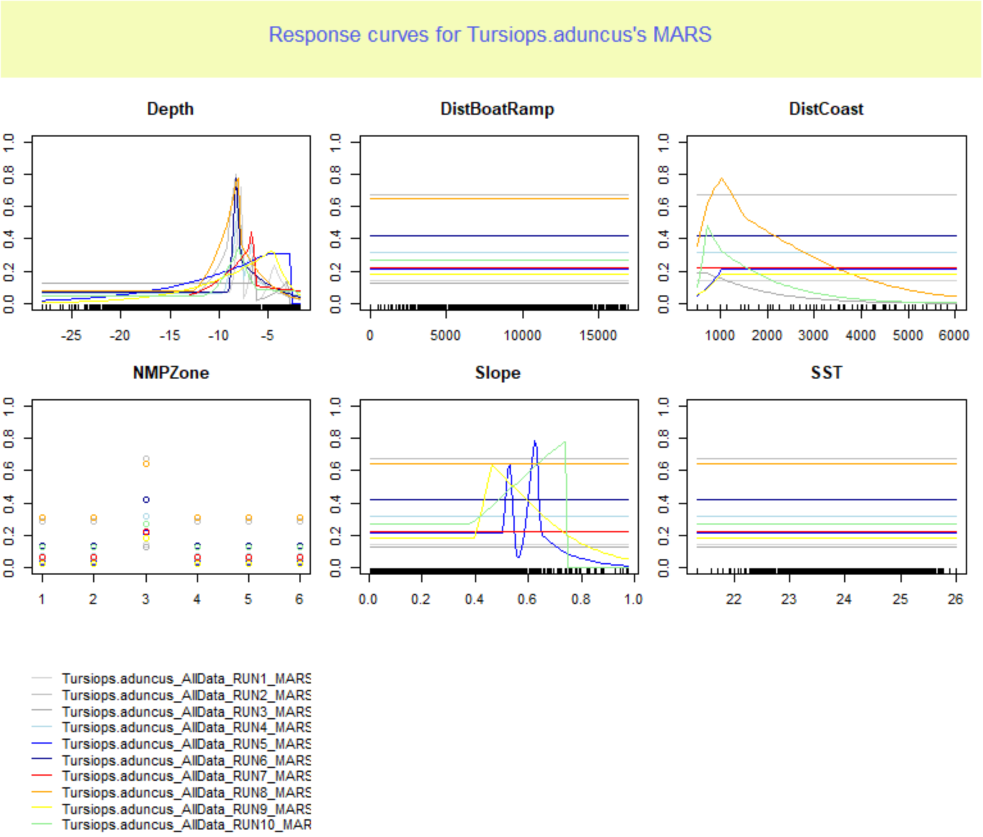
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GLM


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MARS

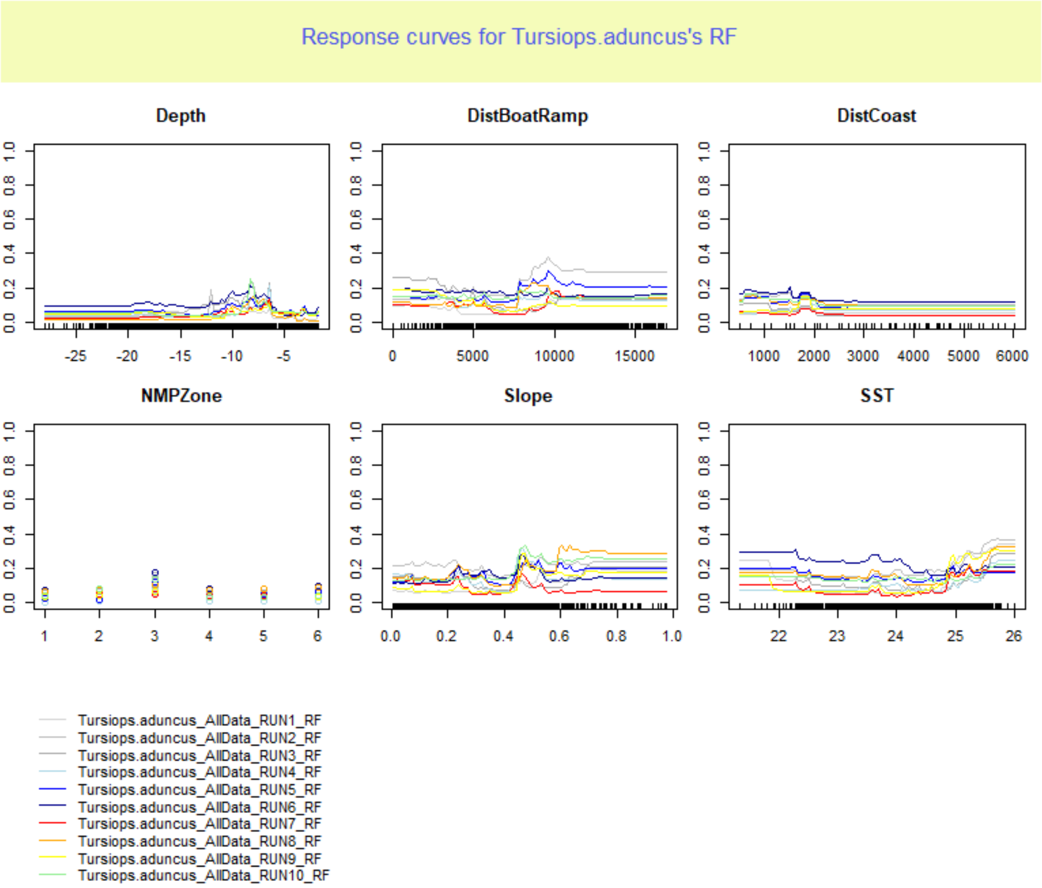
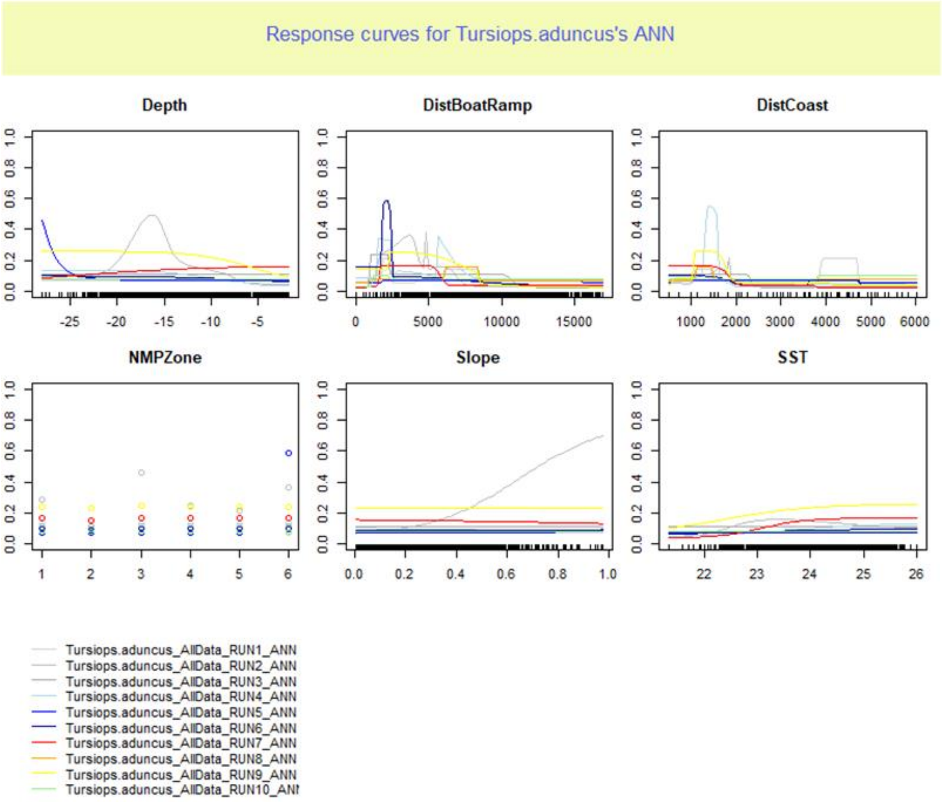
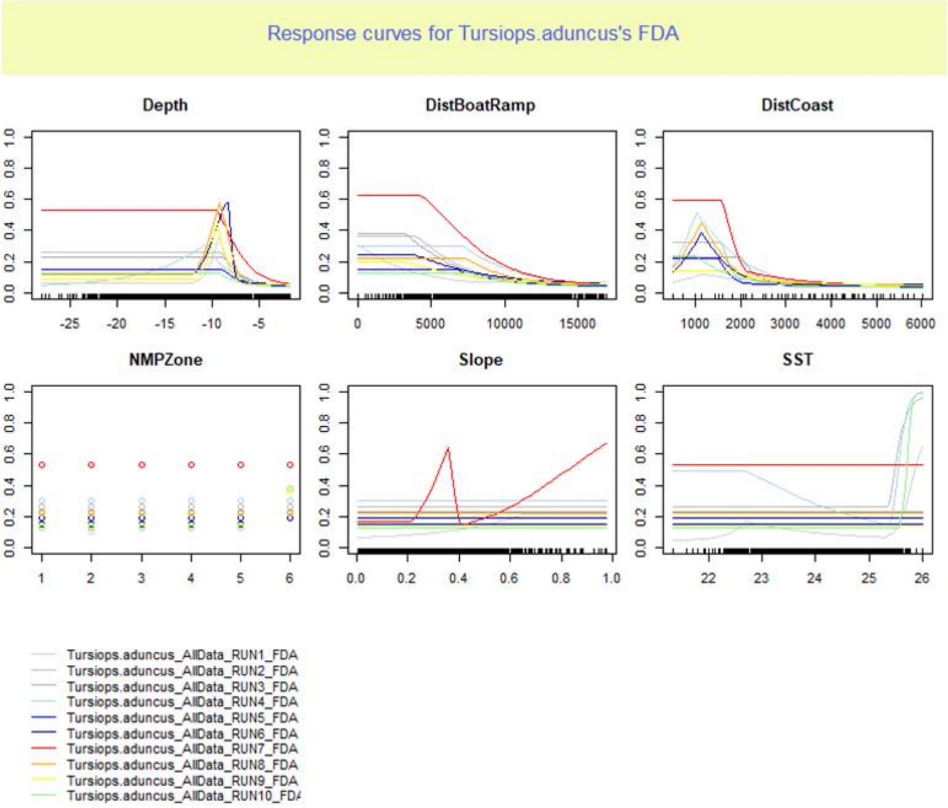
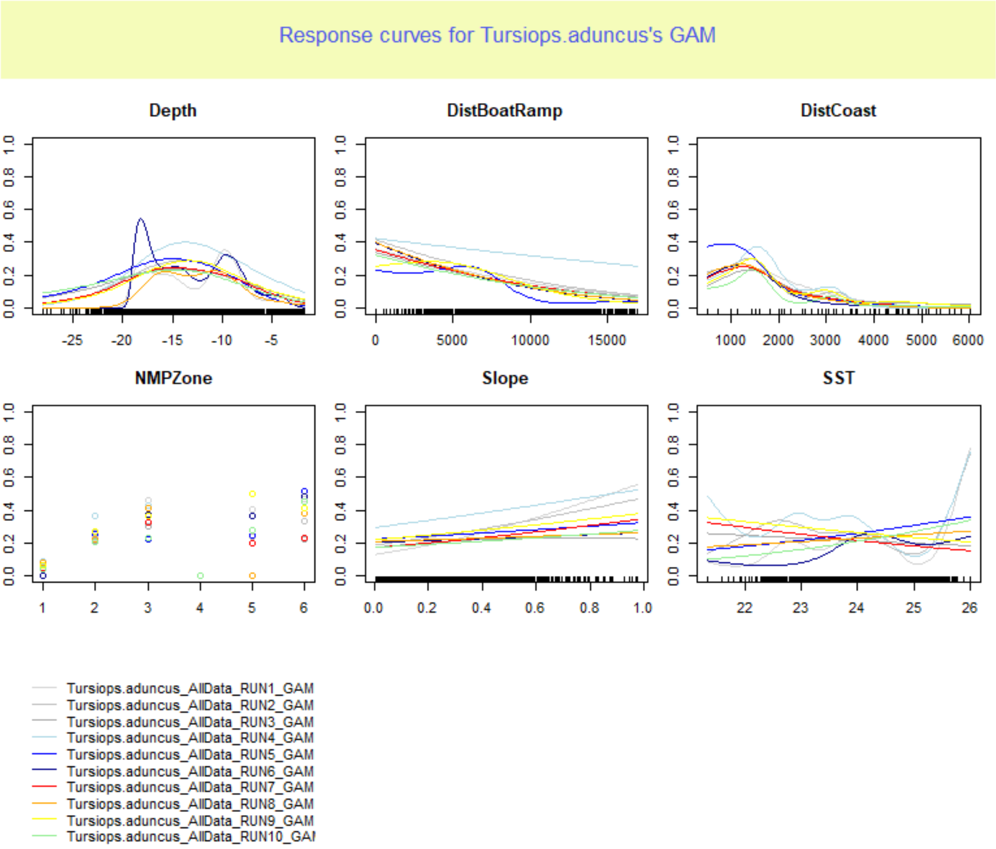


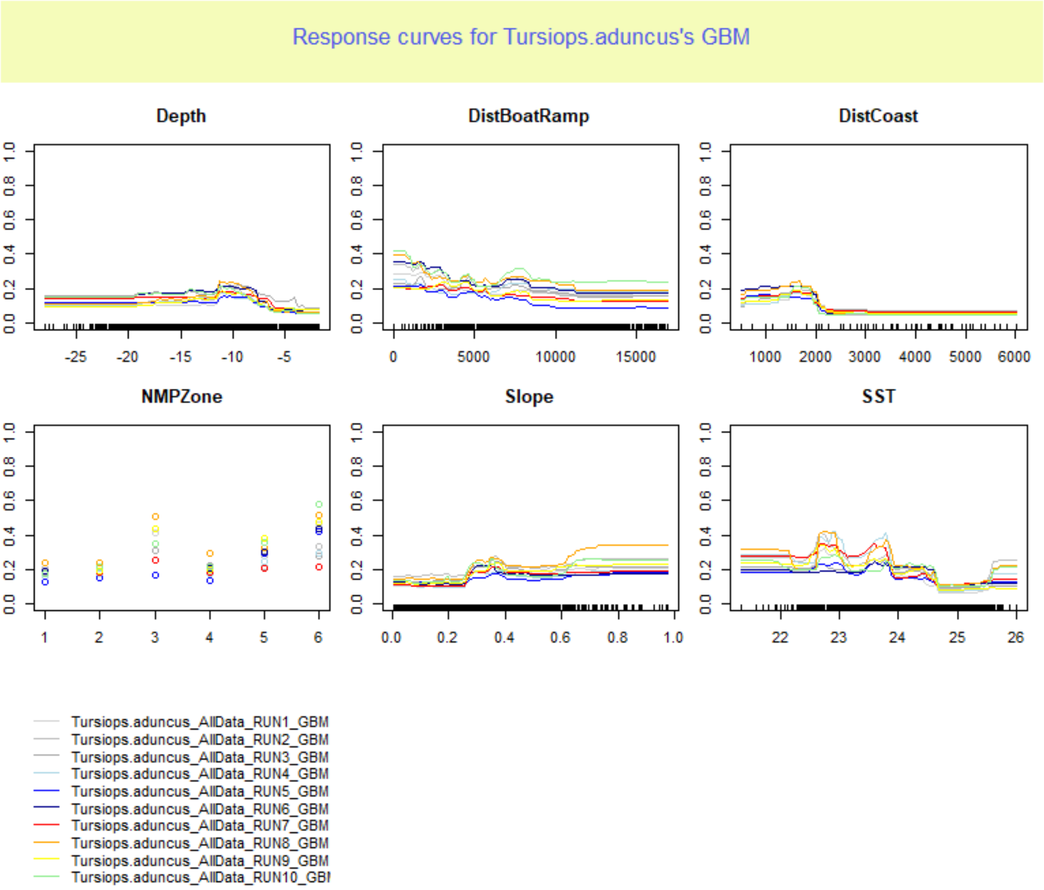
**Figure 9.4:** Response curves of the seven modelling algorithms used in the ensemble to model distribution and habitat preferences of resting Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) groups at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

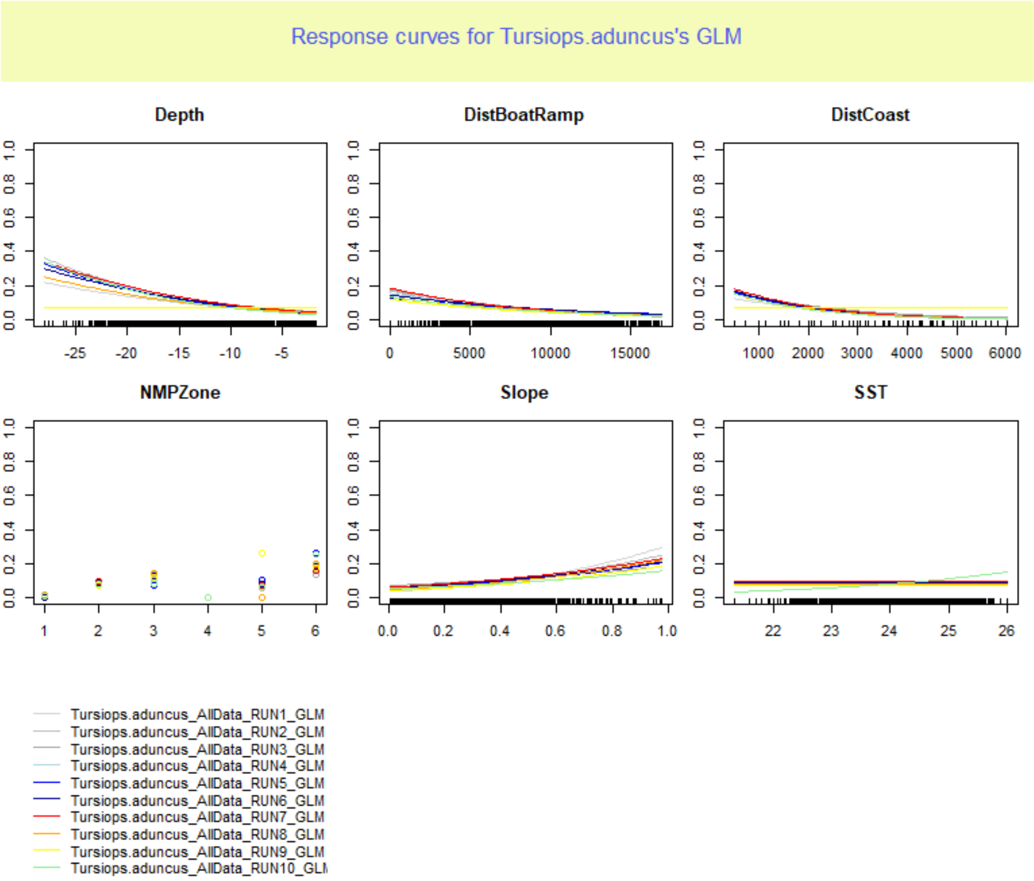
### *S3.5.3 Travelling response curves (entire study area)*

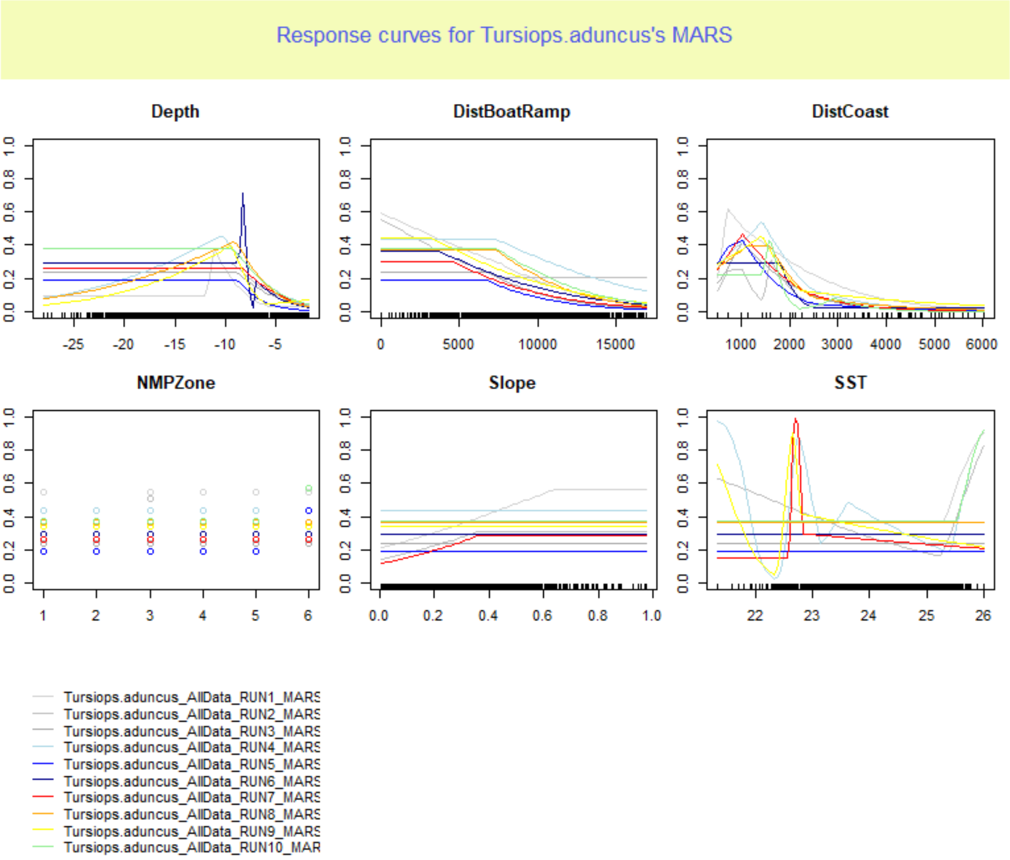





Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GA


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
Tursiops.aduncus_AllData_RUN9_GBM
Tursiops.aduncus_AllData_RUN10_GB


Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
Tursiops.aduncus_AllData_RUN8_GLM
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
NMPZone
Slope
SST
0.0 0.2 0.4 0.6 0.8 1.0
-25 -20 -15 -10 -5
0 5000 10000 15000
1000 2000 3000 4000 5000 6000
1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0
22 23 24 25 26
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

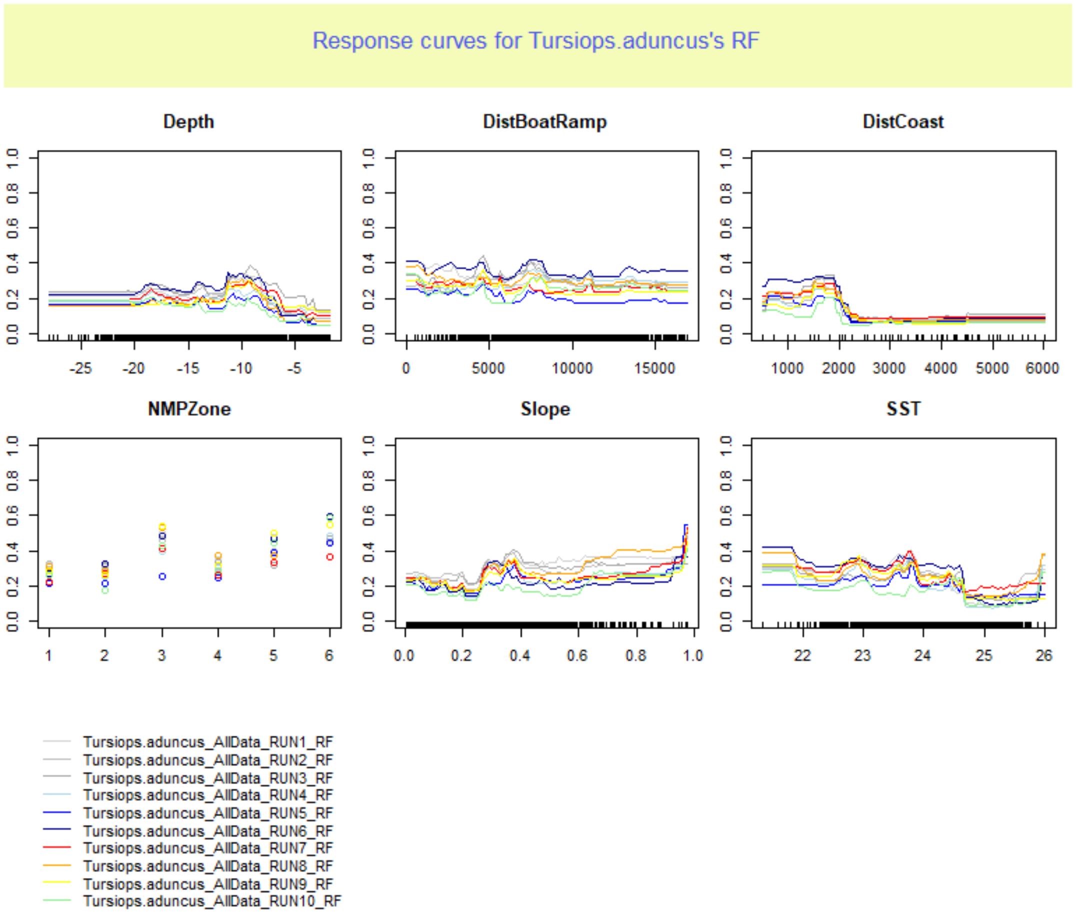
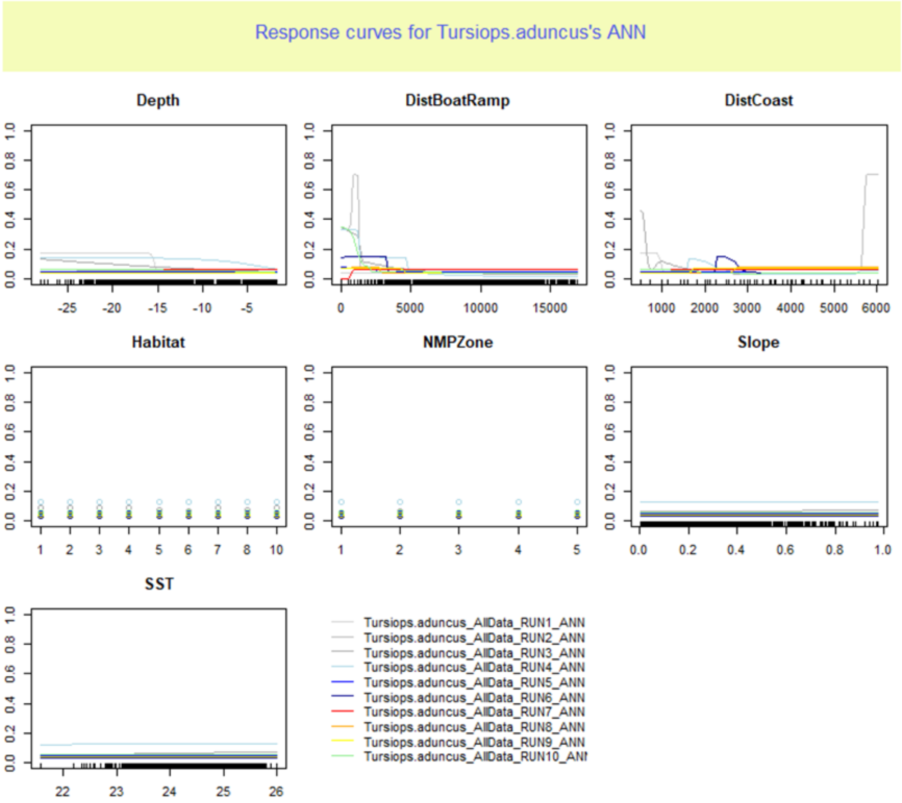
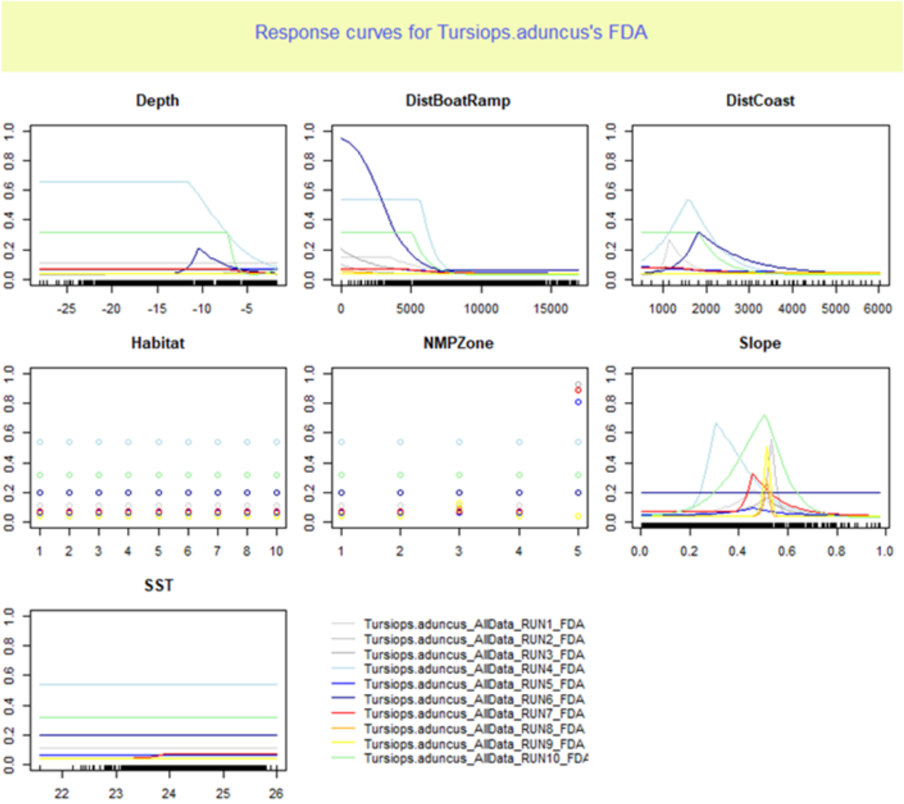


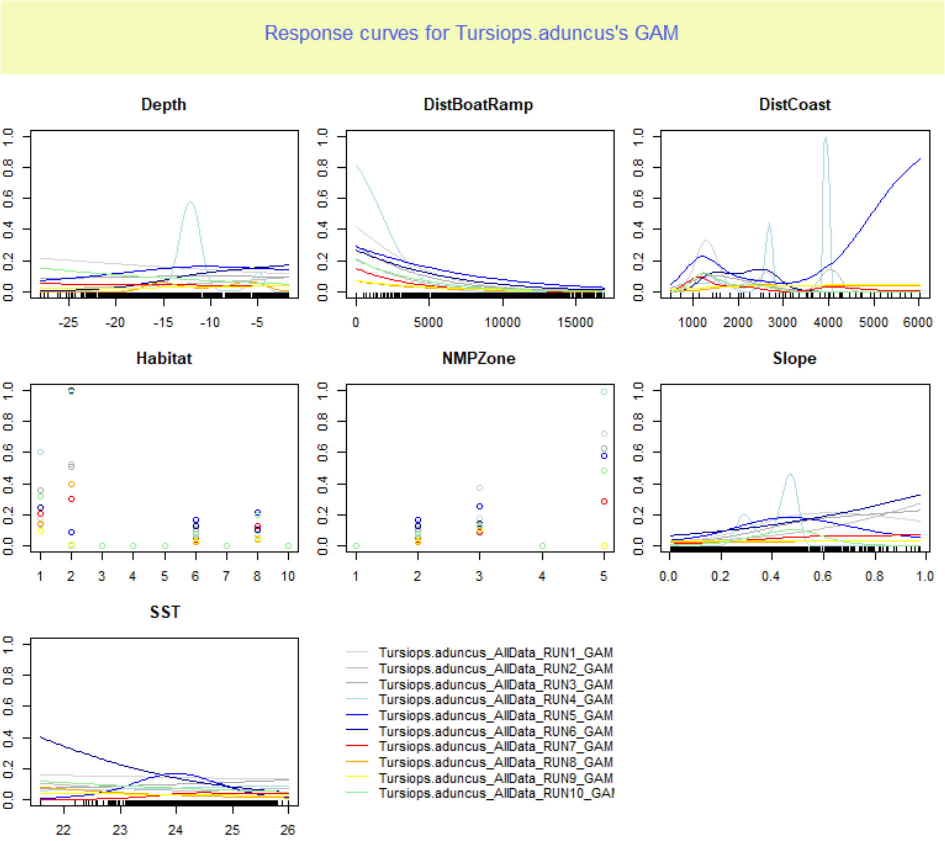
**Figure 9.5:** Response curves of the seven modelling algorithms used in the ensemble to model distribution and habitat preferences of travelling Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) groups at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

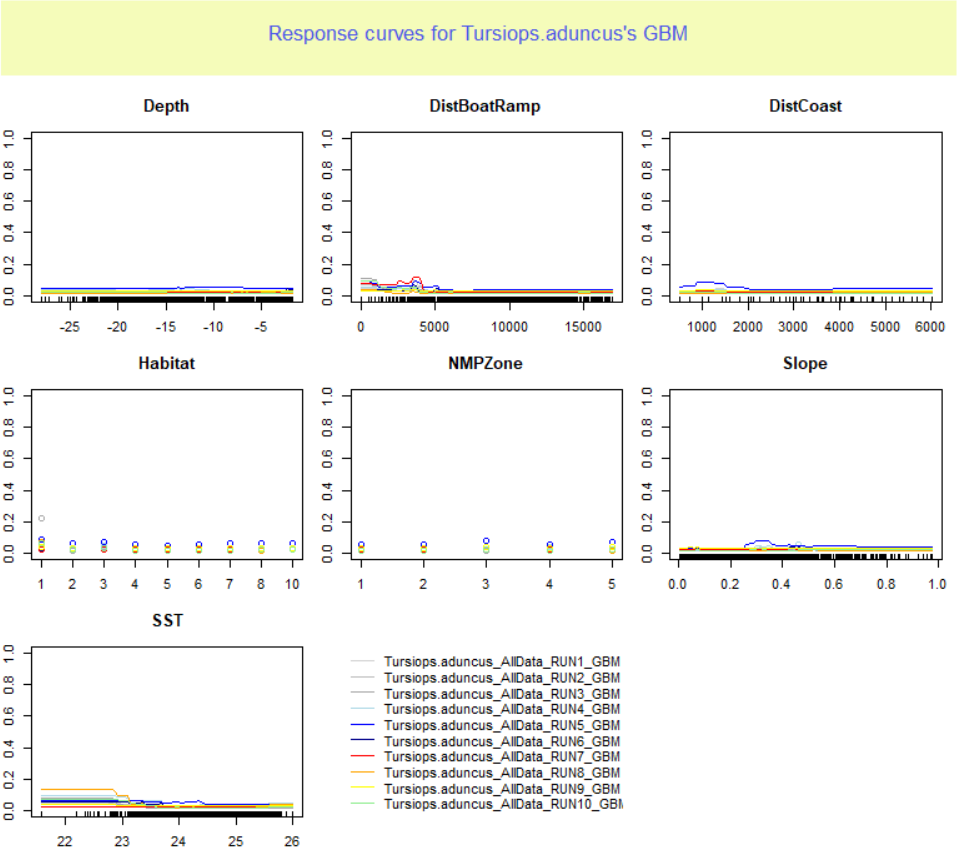
## S3.6 Response curves for behavioural state species distribution models (Ningaloo Marine Park portion of the study area)

### *S3.6.1 Foraging response curves (Ningaloo Marine Park)*

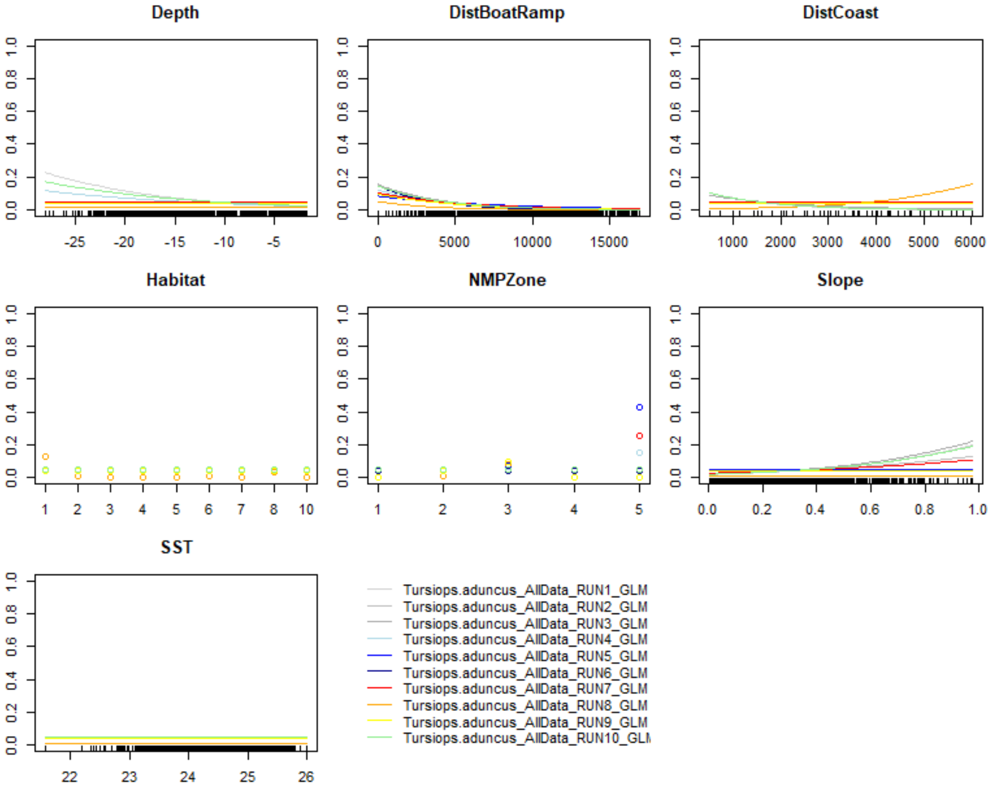




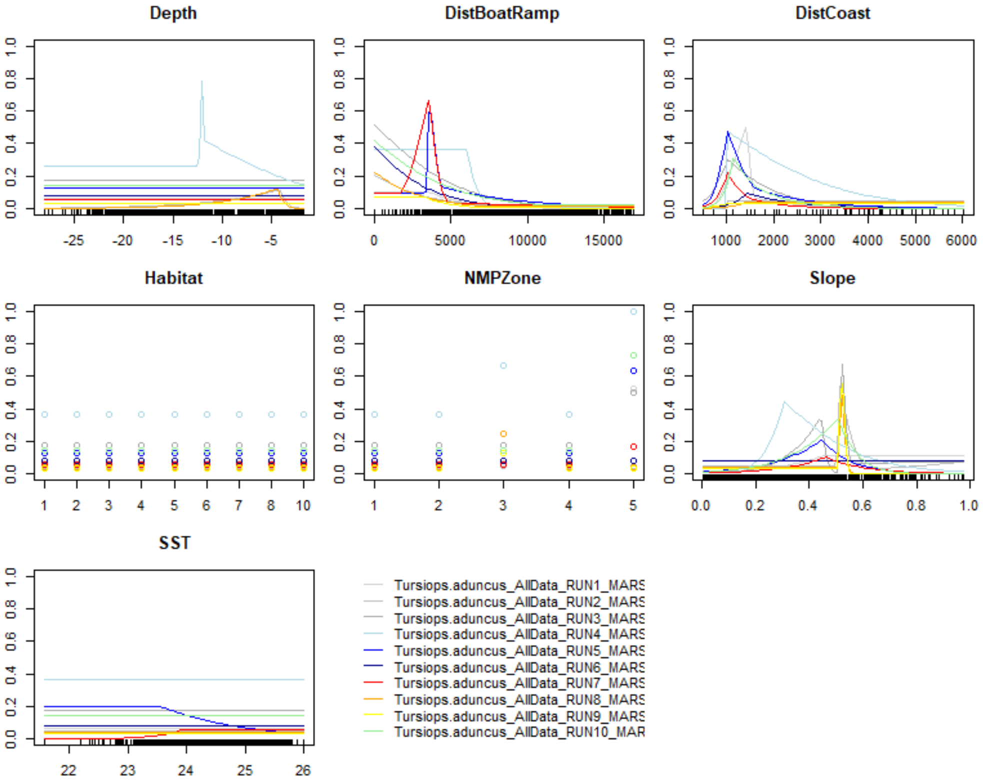

Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GAI


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
Tursiops.aduncus_AllData_RUN9_GBM
Tursiops.aduncus_AllData_RUN10_GBI

Response curves for Tursiops.aduncus's GLM



Response curves for Tursiops.aduncus's MARS



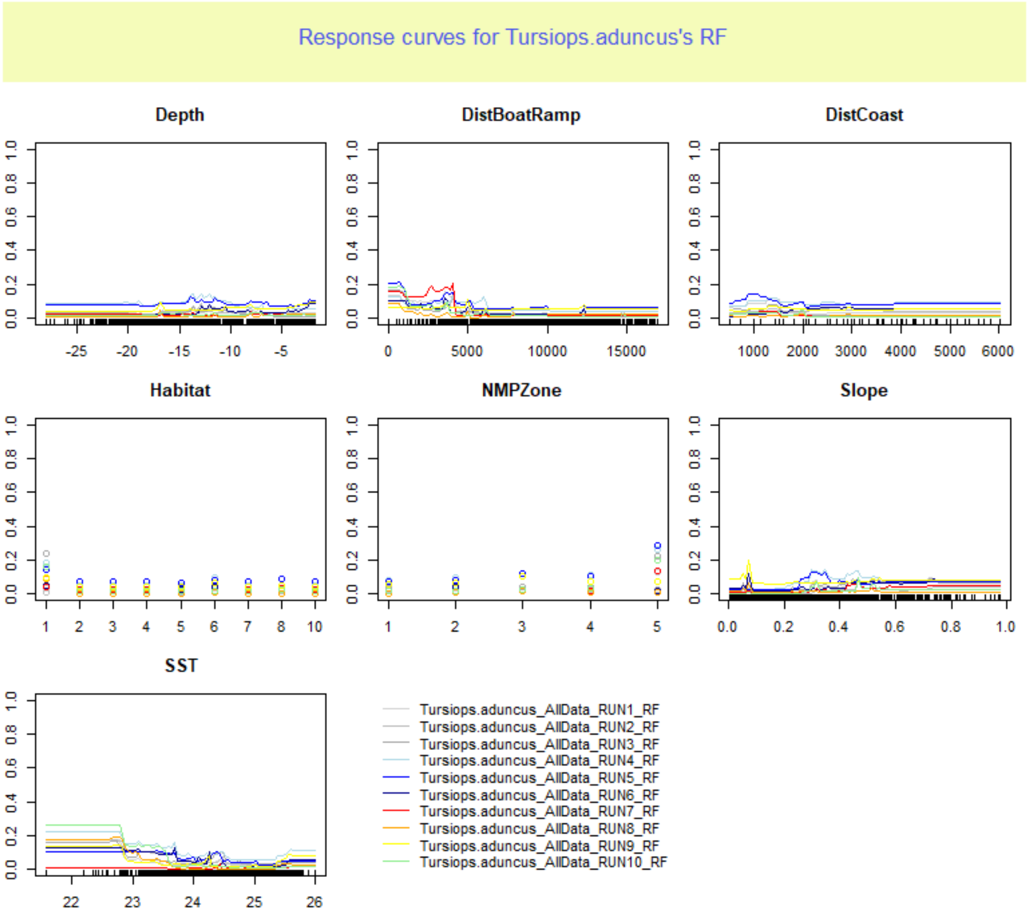
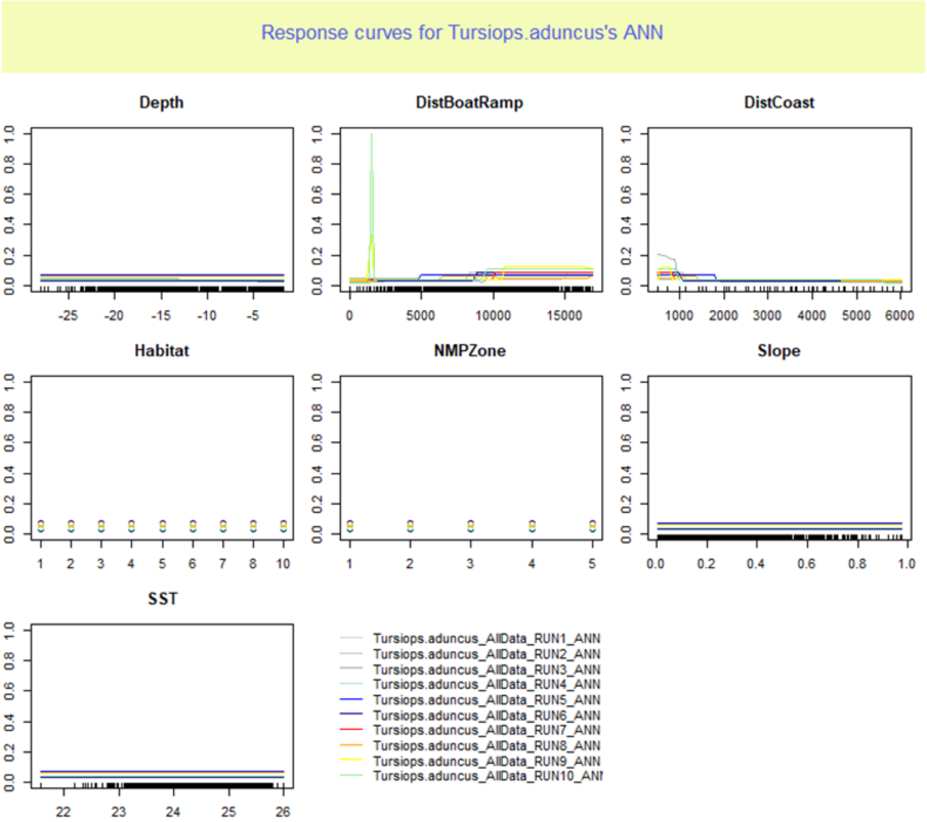
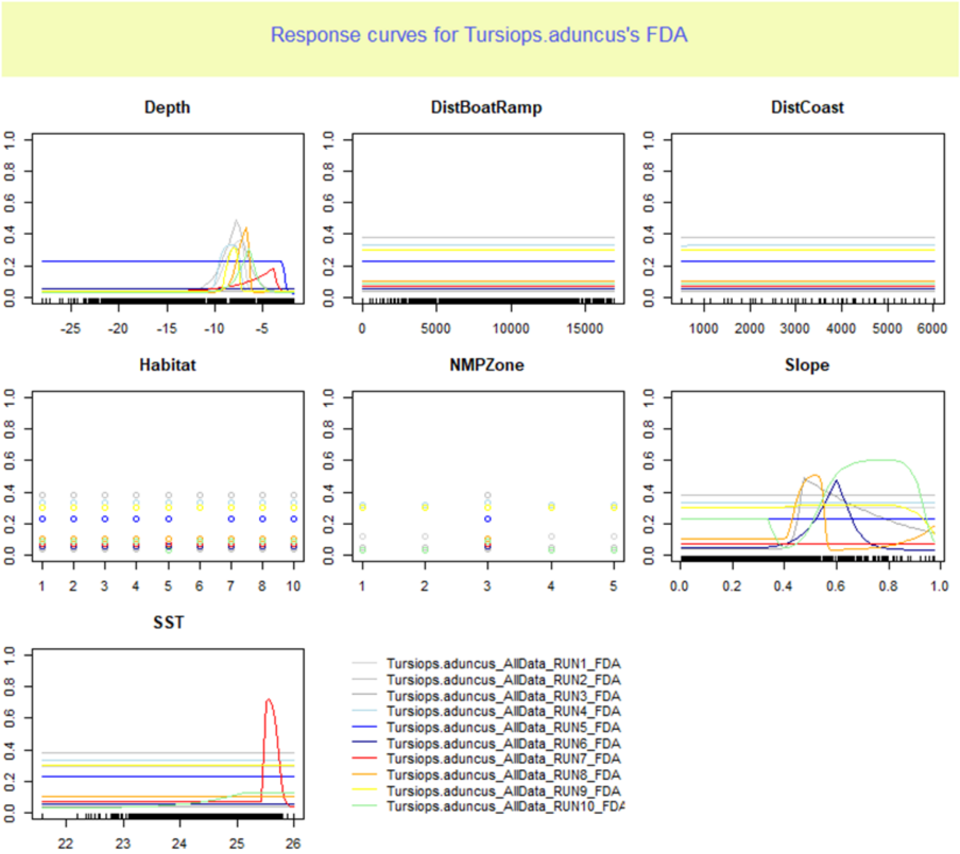


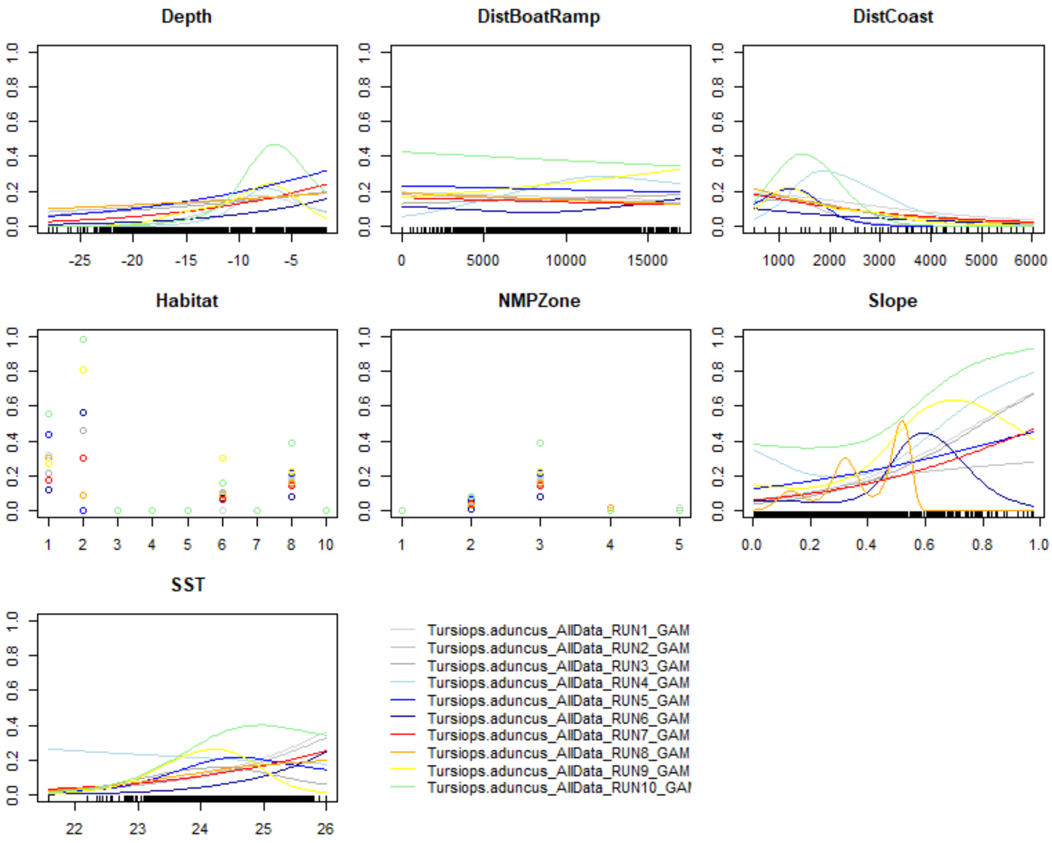
**Figure 9.6:** Response curves of the seven modelling algorithms used in the ensemble to model distribution and habitat preferences of foraging Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) groups within the Ningaloo Marine Park portion of the study area at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

## *S3.6.2 Resting response curves (Ningaloo Marine Park)*

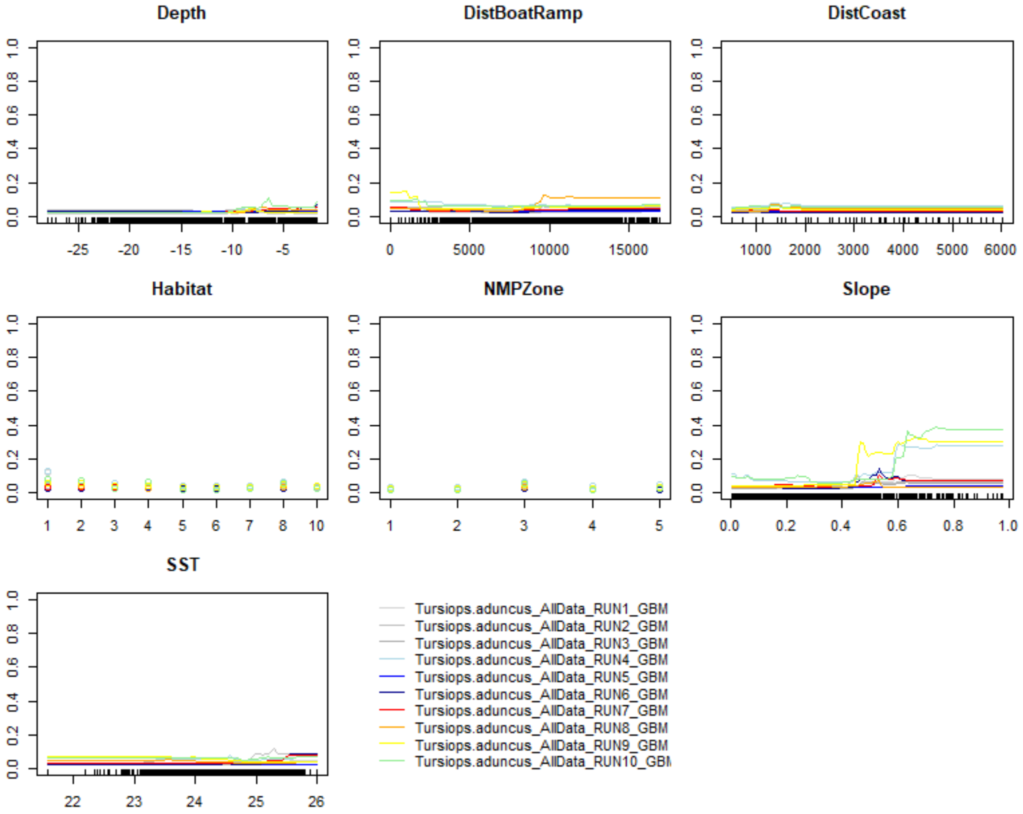


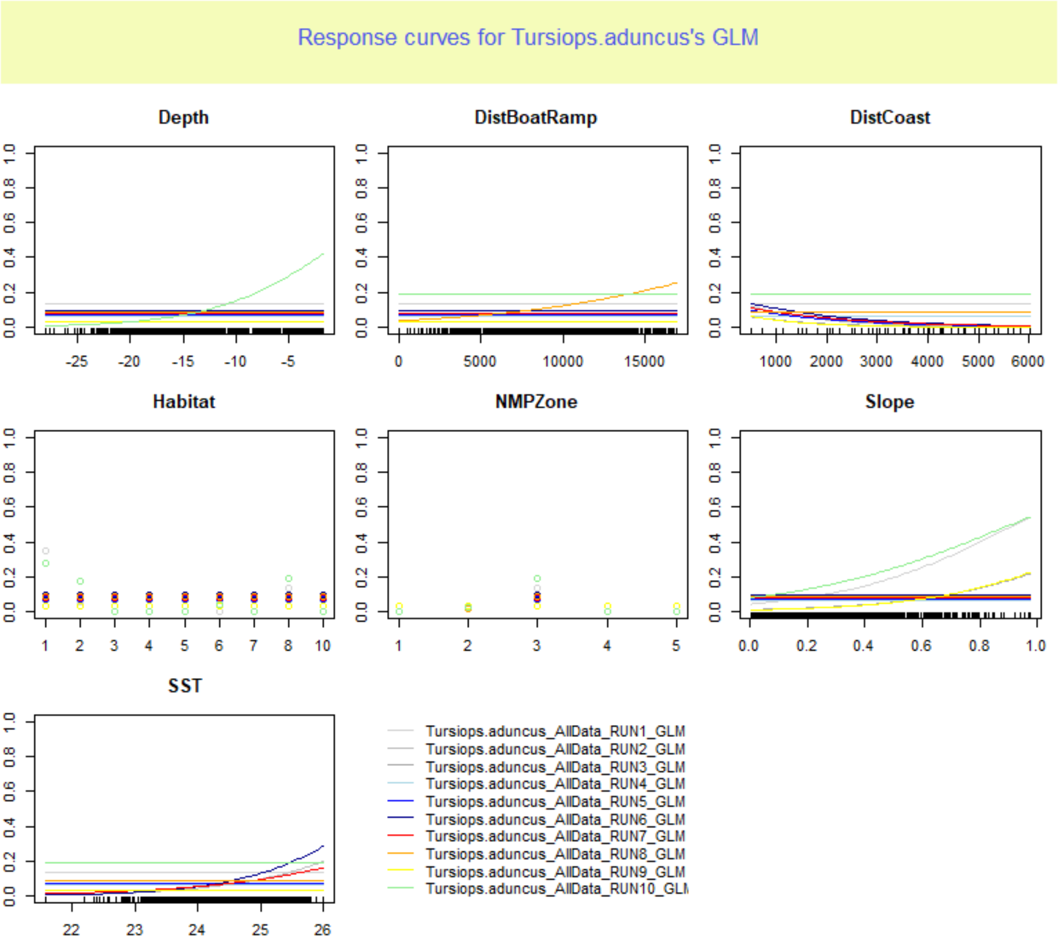


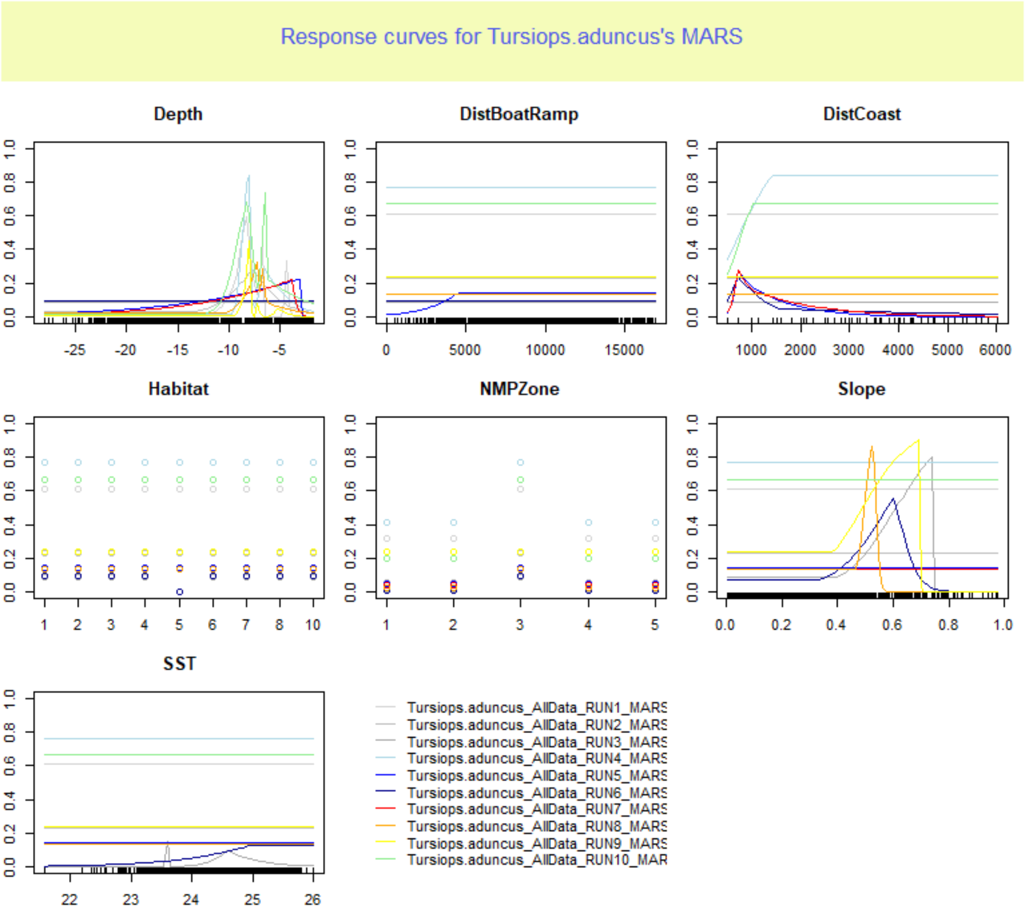
Response curves for Tursiops.aduncus's GAM



Response curves for Tursiops.aduncus's GBM




Response curves for Tursiops.aduncus's GLM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GLM
Tursiops.aduncus_AllData_RUN2_GLM
Tursiops.aduncus_AllData_RUN3_GLM
Tursiops.aduncus_AllData_RUN4_GLM
Tursiops.aduncus_AllData_RUN5_GLM
Tursiops.aduncus_AllData_RUN6_GLM
Tursiops.aduncus_AllData_RUN7_GLM
Tursiops.aduncus_AllData_RUN8_GLM
Tursiops.aduncus_AllData_RUN9_GLM
Tursiops.aduncus_AllData_RUN10_GL


Response curves for Tursiops.aduncus's MARS
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
0.0
0.2
0.4
0.6
0.8
1.0
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_MARS
Tursiops.aduncus_AllData_RUN2_MARS
Tursiops.aduncus_AllData_RUN3_MARS
Tursiops.aduncus_AllData_RUN4_MARS
Tursiops.aduncus_AllData_RUN5_MARS
Tursiops.aduncus_AllData_RUN6_MARS
Tursiops.aduncus_AllData_RUN7_MARS
Tursiops.aduncus_AllData_RUN8_MARS
Tursiops.aduncus_AllData_RUN9_MARS
Tursiops.aduncus_AllData_RUN10_MAR

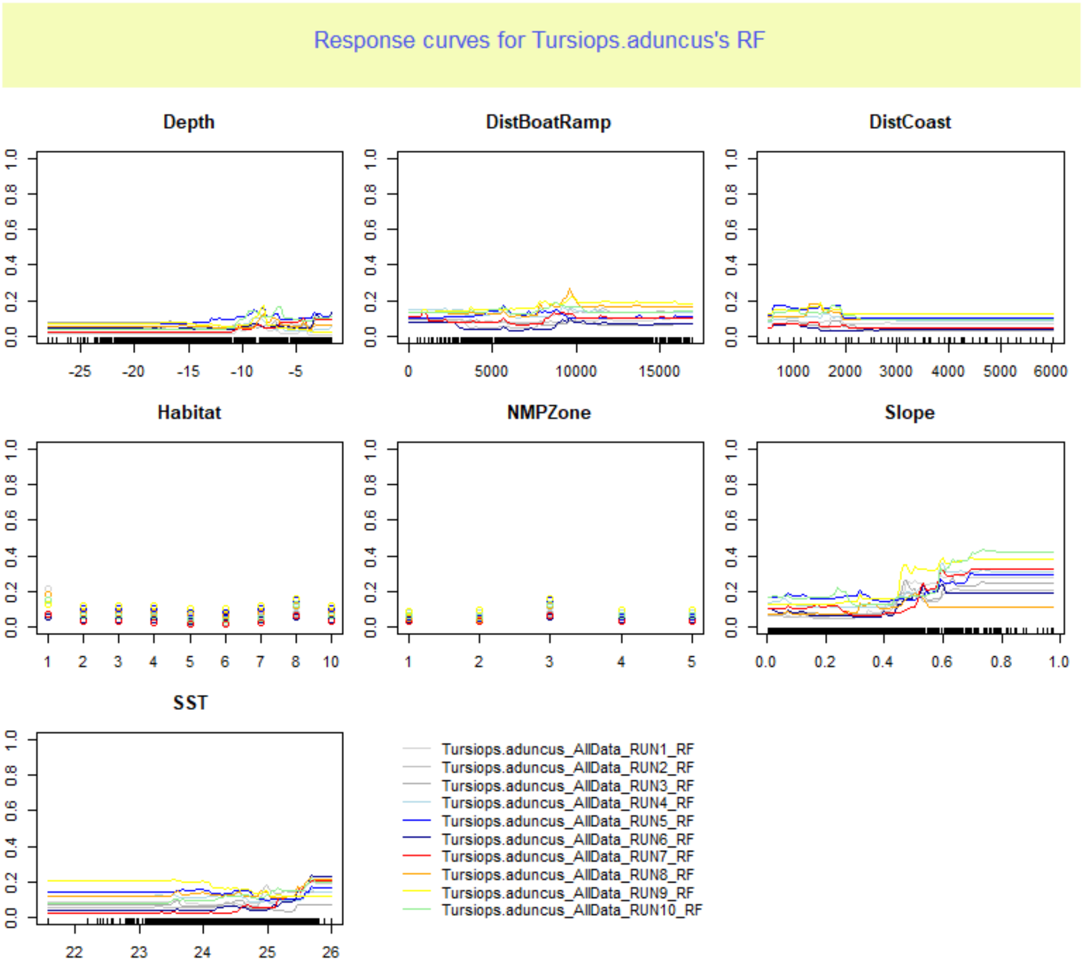
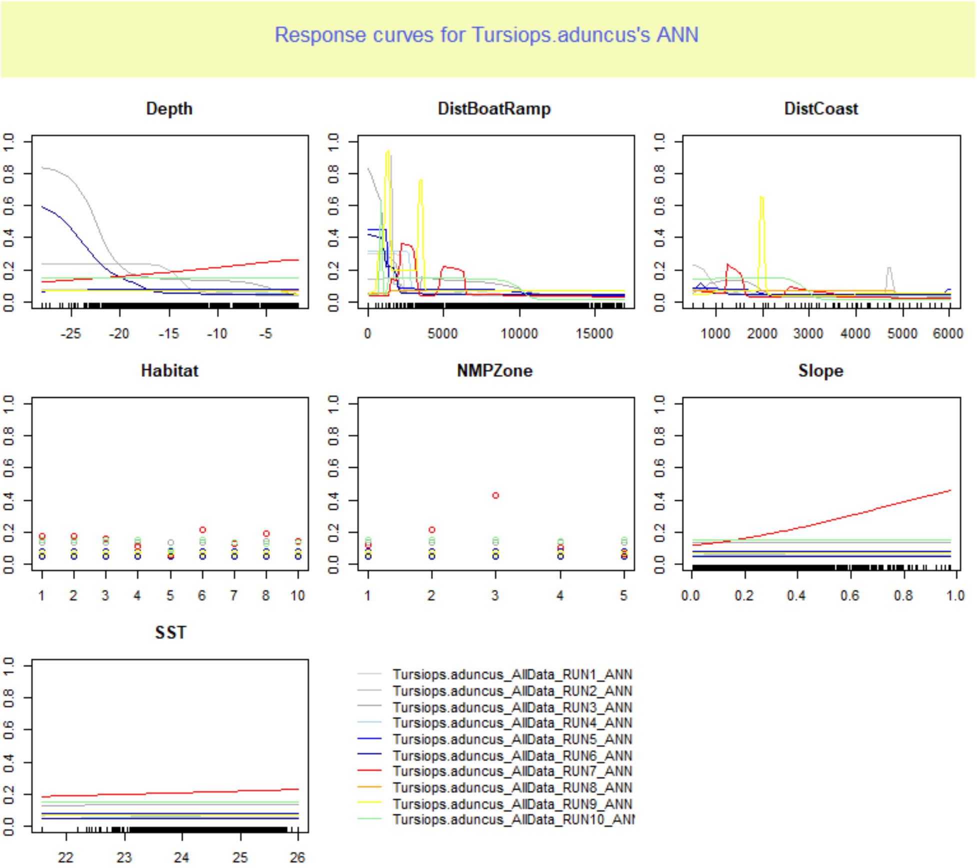
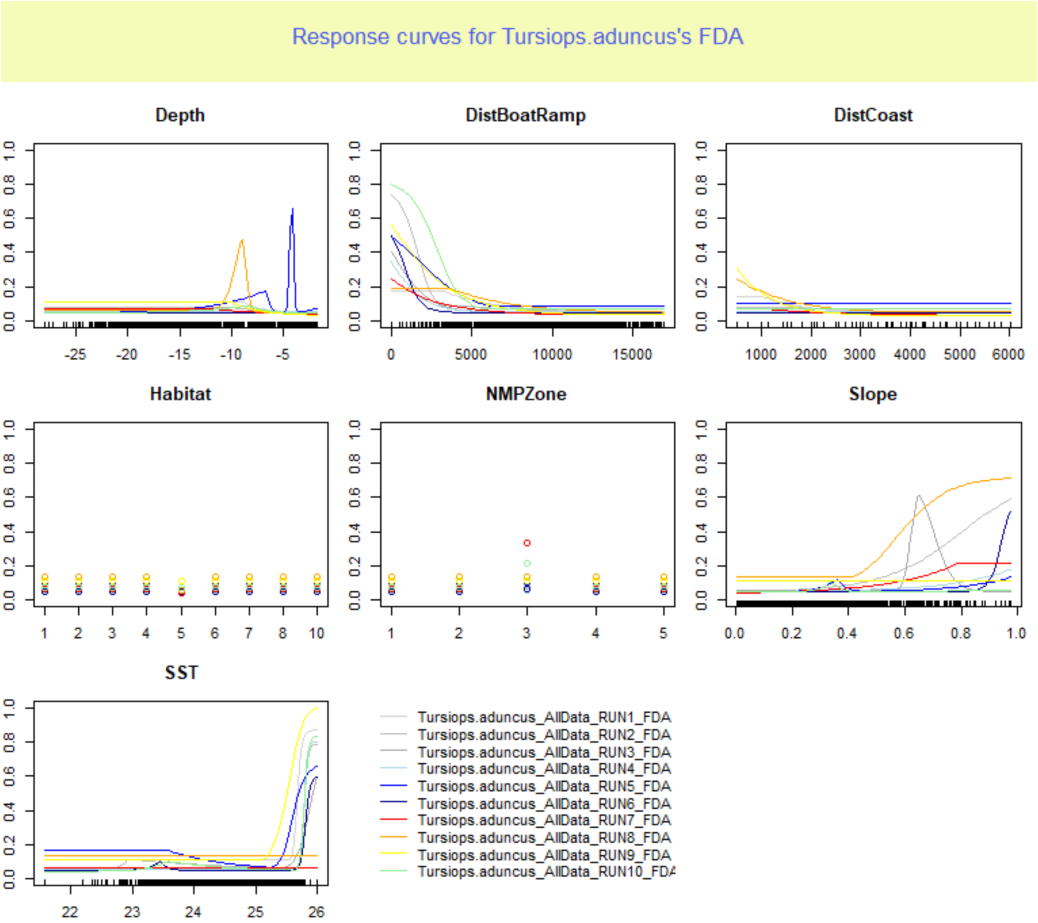
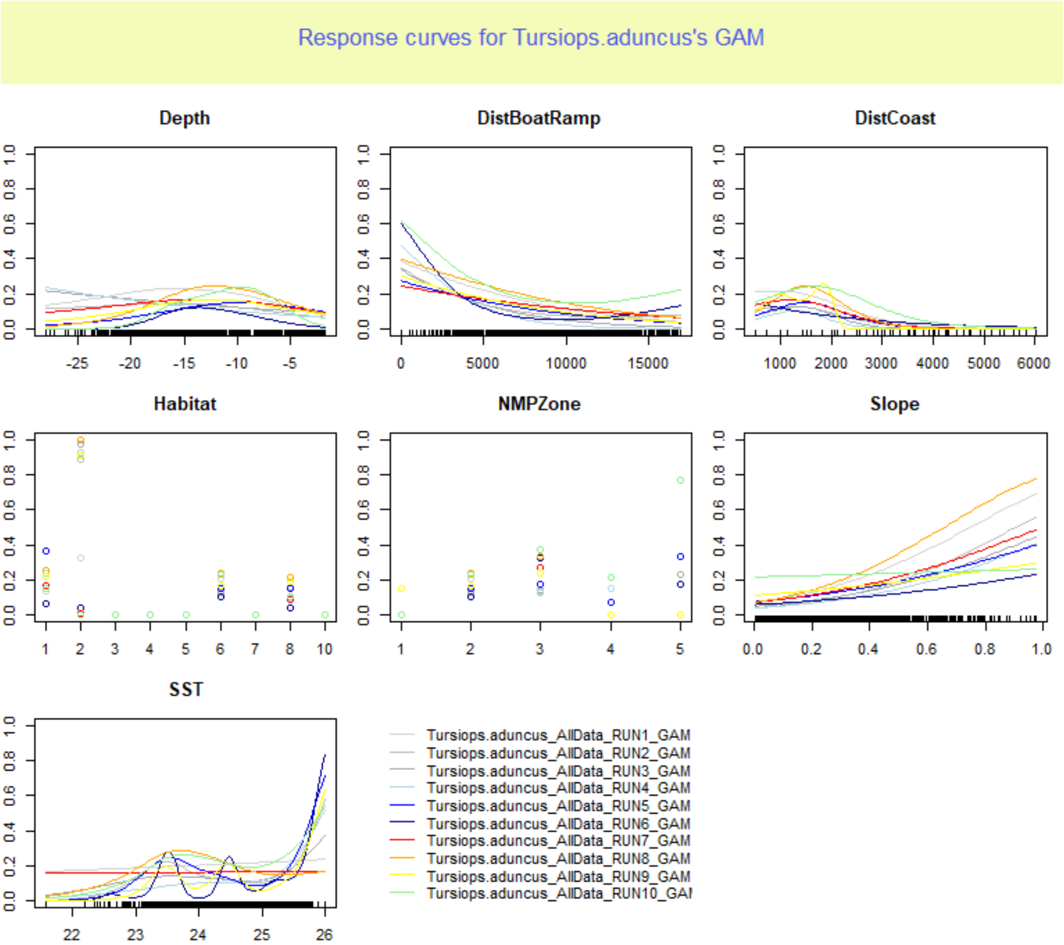


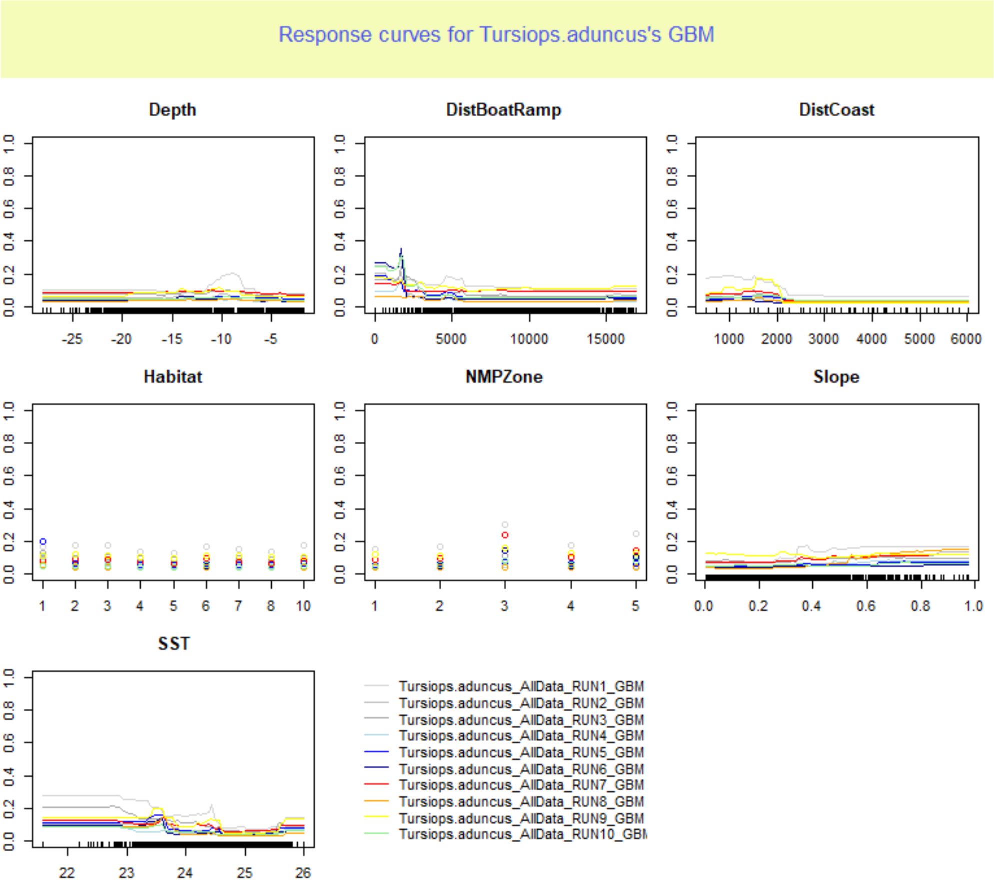
**Figure 9.7:** Response curves of the seven modelling algorithms used in the ensemble to model distribution and habitat preferences of resting Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) groups within the Ningaloo Marine Park portion of the study area at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).

### *S3.6.3 Travelling response curves (Ningaloo Marine Park)*

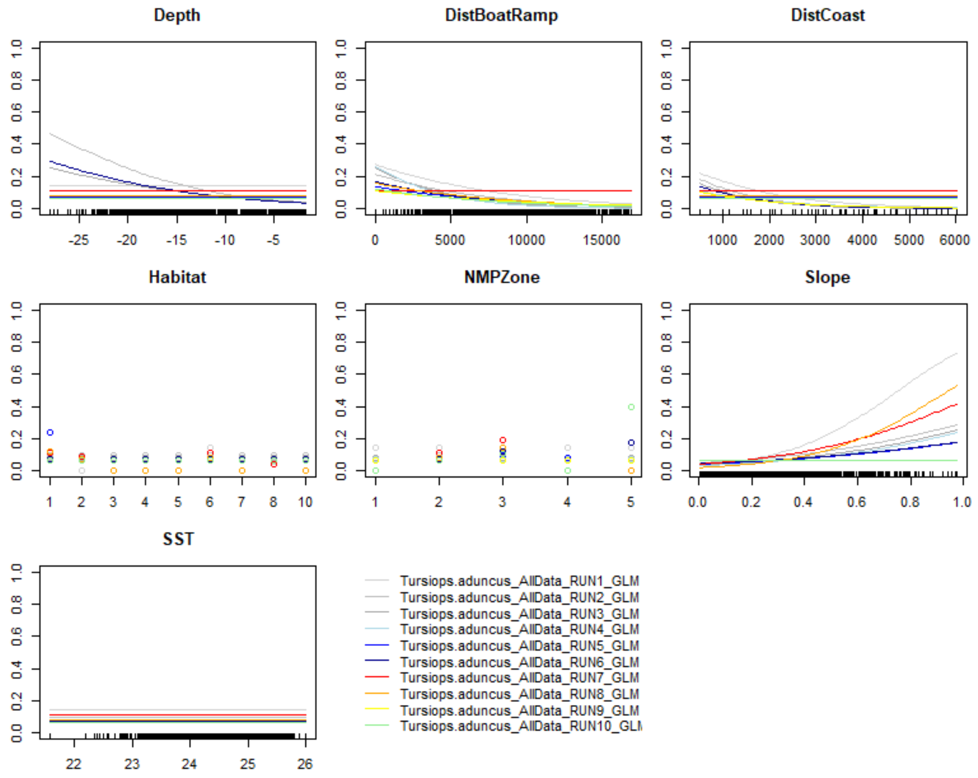




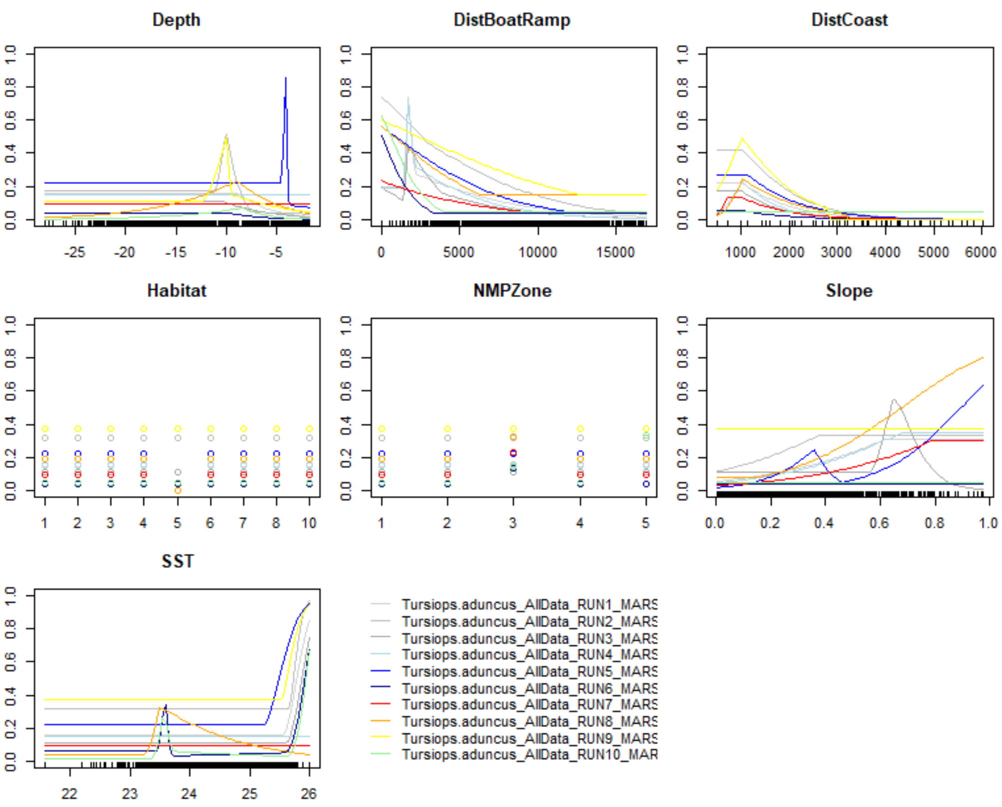

Response curves for Tursiops.aduncus's GAM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GAM
Tursiops.aduncus_AllData_RUN2_GAM
Tursiops.aduncus_AllData_RUN3_GAM
Tursiops.aduncus_AllData_RUN4_GAM
Tursiops.aduncus_AllData_RUN5_GAM
Tursiops.aduncus_AllData_RUN6_GAM
Tursiops.aduncus_AllData_RUN7_GAM
Tursiops.aduncus_AllData_RUN8_GAM
Tursiops.aduncus_AllData_RUN9_GAM
Tursiops.aduncus_AllData_RUN10_GAI


Response curves for Tursiops.aduncus's GBM
Depth
DistBoatRamp
DistCoast
Habitat
NMPZone
Slope
SST
0.0
0.2
0.4
0.6
0.8
1.0
-25
-20
-15
-10
-5
0
5000
10000
15000
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
10
22
23
24
25
26
Tursiops.aduncus_AllData_RUN1_GBM
Tursiops.aduncus_AllData_RUN2_GBM
Tursiops.aduncus_AllData_RUN3_GBM
Tursiops.aduncus_AllData_RUN4_GBM
Tursiops.aduncus_AllData_RUN5_GBM
Tursiops.aduncus_AllData_RUN6_GBM
Tursiops.aduncus_AllData_RUN7_GBM
Tursiops.aduncus_AllData_RUN8_GBM
Tursiops.aduncus_AllData_RUN9_GBM
Tursiops.aduncus_AllData_RUN10_GBI

Response curves for Tursiops.aduncus's GLM



Response curves for Tursiops.aduncus's MARS



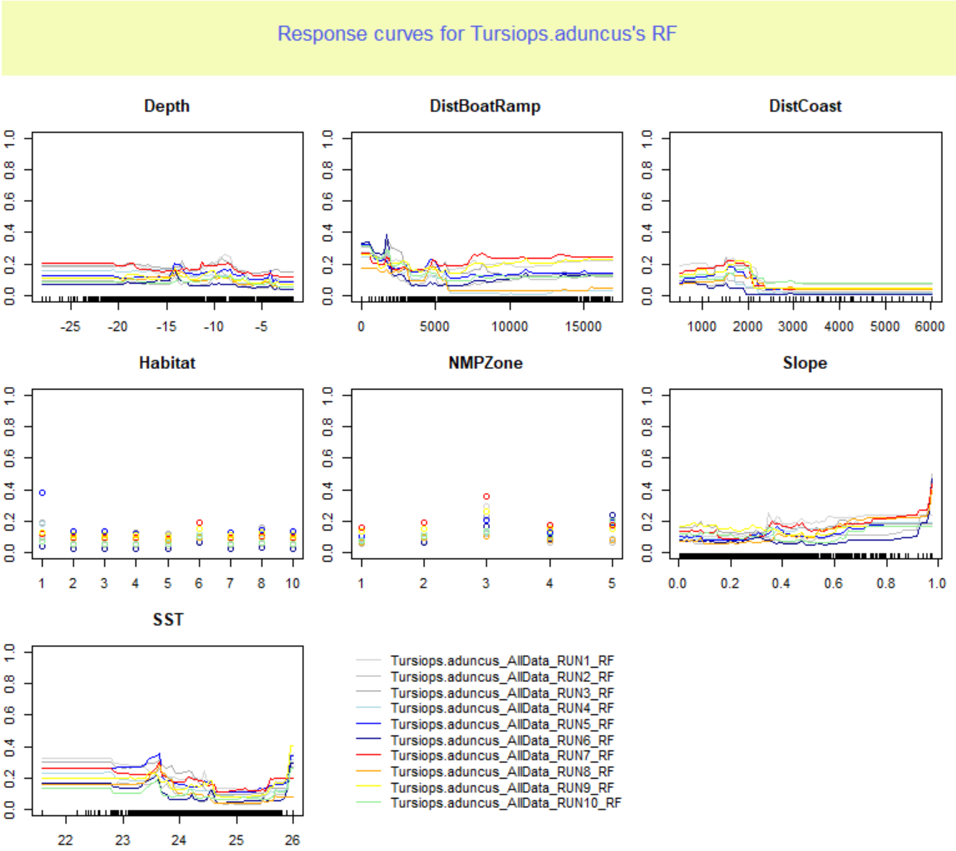


**Figure 9.8:** Response curves of the seven modelling algorithms used in the ensemble to model distribution and habitat preferences of travelling Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) groups within the Ningaloo Marine Park portion of the study area at the North West Cape, Western Australia. (GAM: generalised additive model, GBM: generalised boosted model, RF: random forest, MARS; multivariate adaptive regression splines, ANN: artificial neural network, FDA: flexible discriminant analysis and GLM: generalised linear model).