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Contribution to the Special 'Managing flatback turtles for the future'

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OVERVIEW

# The future for Australia's flatback turtles

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ABSTRACT: The flatback turtle *Natator depressus* is endemic to Australia, where all known breeding sites occur. Flatback turtles have the smallest migratory range of any marine turtle species and nest on coastal islands and the shores of the Australian mainland, from southern Queensland to the north coast of Western Australia. They are threatened by various impacts associated with coastal development, including artificial light, predation from introduced animals, and climate change. They are listed as 'vulnerable' under Australian legislation. In response, research and conservation efforts relating to flatback turtles have expanded over the past decade, which can inform the management of the species for the future. Here, we review the current threats and prospects for the improved status of this species, including the latest research to support the current and future management of flatback turtles in Australia that has been compiled in the *Endangered Species Research* Special 'Managing flatback turtles for the future'. We also outline future research and management needs and emphasise the need for long-term planning underpinned by adaptation pathways and scenarios.

KEY WORDS: *Natator depressus* · Modelling · Climate change · Adaptation · Vulnerability

## 1. INTRODUCTION

Increased human activity and population concentration at the coastal margin have led to declines in population size for many marine species through direct harvesting or, indirectly, through changes in habitat availability, pollution, and disturbance (Nash et al. 2017, Laubenstein et al. 2023). As a result, a range of marine species have been recognised as threatened and are now the focus of conservation activities, including bycatch mitigation, protected area declaration, and habitat enhancement (Duarte et al. 2020). As the 'blue acceleration' and use of our oceans continues to intensify and our oceans become increasingly crowded (Jouffray et al. 2020), these conservation efforts are increasingly challenging because of ongoing impacts, many of which are compounded by climate change (e.g. Laubenstein et al. 2023).

Marine turtles face challenges due to their life history, as they are site-attached for all or part of their life and show philopatry to foraging and breeding sites. Historically, this has led to reduced populations through direct harvesting of nesting adults and eggs (e.g. Kaplan 2005, Pritchard et al. 2022). These life history traits, coupled with temperature-dependent sex determination, also make turtles particularly vulnerable to climate change (Poloczanska et al. 2009, Fuentes et al. 2011). Rates of adaptation to a changing environment are not expected to allow populations to persist

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*in situ* (Laloë & Hays 2023, Fuentes et al. 2024). Marine plastics and entanglements have been implicated in deaths of turtles in a range of locations (Wilcox et al. 2018). As a result of these impacts, most species of marine turtle are recognised as endangered, with 2 species classified as Critically Endangered (https://www.iucn-mtsg.org/statuses). While reductions in fisheries by-catch have occurred in some locations (Putman et al. 2020), without stronger top-down policy and management intervention the remaining threats are expected to lead to declining populations (Merrie et al. 2014).

The flatback turtle *Natator depressus* is endemic to Australia, where all known breeding and most foraging sites occur. Flatback turtles mature at around 16 yr of age (Turner Tomaszewicz et al. 2022) and nest on coastal islands and the shores of the Australian mainland, from Mon Repos in southern Queensland to Murion Islands in the north of Western Australia (Fig. 1). They are the only marine turtle without an oceanic phase in its life cycle, with the post-hatchlings remaining within pelagic continental shelf waters (Kamrowski et al. 2015, Peel et al. 2024). While there is evidence of genetic connectivity among neighbouring rookeries, 7 genetic stocks have recently been proposed, with boundaries of 160–1300 km (FitzSimmons et al. 2020). Across their range, flatback turtles are threatened by various impacts associated with artificial light, predation from introduced animals, marine plastic pollution, coastal development, and climate change, including rising sea levels (DBCA 2017, Department of Environment and Science 2021). Consequently, they are listed as a vulnerable species under Australian legislation. In response, research and conservation efforts relating to flatback turtles have expanded over the past decade, for example, via Western Australia's North West Shelf Flatback Turtle Conservation Program (https://flatbacks.dbca.wa.gov.au/) and locally organised community groups, to inform the management of the species for the future.

## 2. THREATS TO FLATBACK TURTLE POPULATIONS

### 2.1. Coastal activities

While this tropical coastal species is found throughout much of the remote areas of northern Australia, beaches along the northeast and northwest coast have seen much change since European colonisation of Australia. Flatback turtles continue to occupy mainland beaches for breeding (Fossette et al. 2021), which make them vulnerable to a range of human activities (DBCA 2017). Coastal towns and industry, with their associated lights, pollution, and habitat modification now dominate a large extent of the species' range in eastern Australia and the northwest coast of Western Australia. This has meant that traditional nesting beaches have been modified or lost and that disturbance is higher. Light pollution has been identified as a risk to hatching turtles, as it disrupts the critical early migration stage (Kamrowski et al. 2015). Human use of beaches, including with dogs and offroad vehicles (e.g. 4 wheel drive, 4WD), is common close to populated areas, which can disturb nesting adults and nests (DBCA 2017). Development of oil and gas infrastructure has modified beaches through erosion and changes to sand renewal processes, and in some areas, this activity has been intensive (e.g. Whittock et al. 2014). Dredging has occurred in many regions, and while it may be a limited source of direct mortality, may have indirect

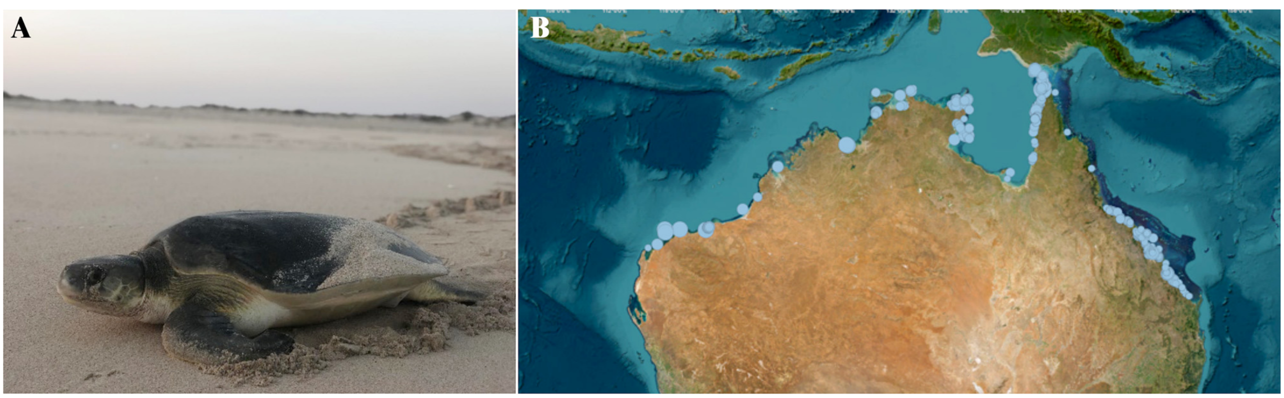


Fig. 1. (A) Flatback turtle (*Natator depressus*) female returning to the ocean after nesting (photo courtesy of Sierra Ison). (B) Distribution of flatback turtle rookeries in northern Australia. The size of the circles represents the size of the rookery. Source: https://apps.information.qld.gov.au/TurtleDistribution/

effects on habitat quality (Whittock et al. 2017). Fishing pressure in the region is generally low after the nationwide implementation of Turtle Excluder Devices (TEDs), although capture in trawl and gillnet fisheries was historically higher, and populations may still be showing signs of this historical mortality (Poiner & Harris 1996). Ghost nets may also cause mortality when adults are trapped. Recreational use of adjacent waters for boating and fishing is high in the eastern and western parts of the flatback turtle's range, lower across the north, but increasing everywhere. Turtles are at risk from vessel strikes from recreational fishing vessels as well as commercial and dredging vessels (Whittock et al. 2017).

### 2.2. Introduced species and natural predation

Australia has many introduced species, some of which are predators of turtle eggs and hatchlings. Foxes *Vulpes vulpes* have caused close to 100% clutch loss for some turtle species, while pigs and dingo (Whiting et al. 2008) are also regionally common predators (King et al. 2023). While adult flatbacks have few predators, sharks (Hounslow et al. 2021) and crocodiles (Whiting et al. 2008) occasionally eat adults and juveniles. Foxes were the most common predator at one mainland flatback nesting beach, with 27% loss of clutches, compared to a background failure rate of 9% (King et al. 2023). Control measures can significantly reduce this predation rate and are an active focus in some management areas. Clutches are also predated by native species, including goannas *Varanus gouldii*, night herons *Nycticorax caledonicus*, and silver gulls *Chroicocephalus novaehollandiae*. Where foxes have dug into nests, access to eggs and hatchlings is easier for smaller predators such as goanna, bandicoots (Family Peramelemorphia), and ghost crabs (King et al. 2023). Increases in predation from native species that are increasing in abundance or presence due to human activities, such as silver gulls, or predatory fish aggregating around human structures such as jetties (Wilson et al. 2019), have been shown to reduce the number of surviving hatchlings. Management of native species is more controversial than for introduced species (Hobday et al. 2015), but must be considered when hyper-abundance has occurred because of human activity.

### 2.3. Climate change

Climate change will directly impact flatback turtles through sea-level rise and loss of nesting habitat, while warming temperatures will affect sex ratios of hatchlings (Gammon et al. 2020). Indirect climate impacts may be felt through changes in habitat quality, such as loss of foraging grounds. Given their wide distribution across northern Australia, impacts of climate change will be stock-specific, and responses may depend upon the degree of impact to the overall stock and the extent of genetic connectivity between neighbouring stocks (FitzSimmons et al. 2020).

Sea-level rise can contribute to beach erosion, reducing the availability and stability of nesting sites for marine turtles (Gammon et al. 2023). It can also increase the risk of nests being inundated by seawater, especially during high tides or storm surges. Saltwater intrusion into nests can be detrimental to the developing turtle embryos, affecting hatching success. Further, sea-level rise contributes to more frequent and intense storm surges during extreme weather events. Coastal nests and nesting females may be more exposed to the impacts of storm surges, leading to increased mortality rates and reduced nesting success. Long-term changes to beach topography and vegetation due to warming may affect the success of nesting and the survival of eggs. One approach to this change has been to reprofile beaches to increase sand depth and coverage. In response to long-term declines in nesting success on Raine Island, the world's largest green turtle *Chelonia mydas* rookery, strategic movements of beach sand to increase nesting habitat above tidal inundation boosted hatchling production by as much as 640000 over a 5 yr period (Smithers & Dawson 2023). This intervention may be needed in other locations occupied by flatbacks in future, including Barrow Island.

Warmer air temperatures can also affect marine turtles, as they exhibit temperature-dependent sex determination, where the temperature during the incubation period influences the sex of the hatchlings (Jensen et al. 2018, Gammon et al. 2020). Warmer temperatures often result in more female hatchlings, while cooler temperatures lead to more males. With rising global temperatures, there is concern that this could skew the sex ratio of marine turtle populations, potentially affecting their reproductive dynamics. While the femininisation of marine turtle clutches due to warming has been widely reported (e.g. Jensen et al. 2018), there are locations where local conditions remain cooler, allowing a more balanced sex ratio of hatchlings (Staines et al. 2023). Mounting evidence indicates that air and sea temperatures will increase over time, and projections indicate that marine turtles will not be able to shift their phenology or adapt their behaviour fast enough to keep up with the pace of warming (Laloë & Hays 2023). Extreme events, such as heatwaves, may also stress breeding adults and hatchlings. Small-scale interventions such as nest cooling with seawater or shading (Smith et al. 2021, Young et al. 2023) have been shown to increase the proportion of male hatchlings in marine turtles and could be applied to flatbacks, although the best hatchling sex ratio to ensure continued breeding success in adult turtles is yet to be determined for any species.

### 2.4. Indirect impacts

The ongoing changes to coastal environments associated with industrial and urban growth described above can also result in indirect impacts on important habitats, including disturbance and loss of foraging or nesting areas. Generally, however, these indirect impacts are challenging to quantify, and levels of activity that would lead to population impacts are generally not known. For example, there is currently only limited understanding of the impact of foraging area disturbance on the population dynamics and reproductive output for the affected turtles. Habitat modelling and predictive-based ecology may be needed to identify future habitats, their degree of impact, and ensure protection.

## 3. PAPERS IN THE *ENDANGERED SPECIES RESEARCH* SPECIAL 'MANAGING FLATBACK TURTLES FOR THE FUTURE'

Eight papers in this Special contribute knowledge that can be used in the management of flatback turtles. Each of the papers is summarised here.

In the face of rapid environmental change, the protection of important migration pathways and foraging areas is critical (Peel et al. 2024). Abrantes et al. (2024; this Special) used a novel combination of satellite tracking and stable isotope analysis to identify 3 main foraging areas for flatback turtles in eastern Queensland. They demonstrated that $\delta^{13}C$ and/or $\delta^{15}N$ values can be used to identify foraging regions. A side benefit of this approach was the regional isoscape, which should be useful for ongoing studies of habitat use of flatback turtles and other migratory marine species. Habitat use for adults can be determined with satellite tags and direct observations, but different approaches are needed for hatchlings, and at-sea distributions are unknown. Wilson et al. (2023; this Special) used an ocean circulation model to simulate turtle dispersal up to 30 d after hatching at 12 rookeries in Western Australia and to identify core use areas, all on the continental shelf. The overlap between core areas and light pollution and infrastructure were calculated and revealed that, early in dispersal, at least one threat was present in each core area, but less than half of the area used between Days 25 and 30 was exposed to threats. In the absence of empirical data on hatchling distribution, these approaches will continue to be important in identifying areas where threats are concentrated and in developing mitigation approaches, if needed, to any impacts.

Four papers in the Special reported on development and evaluation of intervention options for flatback turtles to increase likelihood of population persistence in the future (van Putten et al. 2023, Hobday et al. 2024, Richards et al. 2024, Tuohy et al. 2024; all this Special). Hobday et al. (2024) generated a range of intervention options that could be used to reduce impacts from 6 primary threats. These were ranked using an intervention prioritization tool based on their economic cost, implementation feasibility, social acceptability, and perceived effectiveness in maintaining or increasing future turtle populations. Similar methods have been used for other species (e.g. Alderman & Hobday 2017) and can guide research and conservation investment decisions by managers. Richards et al. (2024) then use an age-based, spatially implicit, population model for the north-west shelf flatback turtle to estimate the long-term outcomes for a range of these conservation interventions. Analysis of the model showed that young adults contribute most to population growth, however, this is the most difficult life-stage to manipulate in the field. As observable outcomes of interventions on eggs or hatchlings cannot be seen for many years due to first breeding beginning at an age of 16 yr, this type of model can be used to rapidly estimate the impacts of climate change and conservation interventions on turtle dynamics and help guide monitoring efforts to assess their value for real populations. One surprising result from the model was that if environmental warming increases, the probability that offspring are female increases, and if adult female bias reduces mating success, then turtle populations may show stability or increases before crashing, often with a long delay.

As noted earlier in this paper, not all the interventions that are possible might be acceptable to managers or to the public-at-large. Tuohy et al. (2024) assess the social acceptability of the intervention options developed by Hobday et al. (2024). Engaging with the public can be time-consuming, so previous studies have used expert opinion as a predictor of social acceptability; however, the assumption that the social acceptability of interventions is the same for the public and experts is largely untested. Tuohy et al. (2024) used surveys of experts and community members in 2 towns adjacent to rookeries to assess the social acceptability of 24 interventions. Surprisingly, residents generally ranked interventions that directly intervene with human behaviour (e.g. reducing 4WD access to beaches) or the environment as more acceptable than those that directly targeted turtles (e.g. nest relocation), while experts tended to favour direct turtle interventions. Experts and community members differed in their acceptability of different options, which highlights the importance of understanding the social acceptability of interventions before implementation, particularly when interventions might be controversial or restrict human behaviour directly. Where interventions are potentially controversial (e.g. culling of native species), efforts in engagement and communication strategies to build social acceptability may be warranted before commencing interventions. Working in the same communities, van Putten et al. (2023) examined attitudes to turtle conservation and found broad agreement between respondents from both locations on the most and least acceptable interventions. Interventions that limit human behaviour, as opposed to interfering with the species themselves, are likely to be most socially acceptable. Tuohy et al. (2024) and van Putten et al. (2023) both provide a way to examine the attitudes to conservation intervention, which is important to avoid conflicts and build community support for conservation efforts.

Long-term climate change and other stressors, such as industrial development, are changing the environment in which flatbacks live and are projected to continue for many decades. How do conservation managers and policy makers explore the range of future conditions that will lead to conservation success? Hobday et al. (2025; this Special) develop illustrative scenarios spanning a range of plausible futures in which the intensity of climate change and development vary. They show an illustrative set of adaptation pathways that allow consideration of alternative conservation management and policy options and the lead times for these options. These approaches can be used to future-proof thinking for conservation managers and should be used widely for improved outcomes in natural systems.

Animal health may be one of the early warning signs of population stress. Blood reference intervals (RIs), which are a general measure of animal condition, are available for 6 species of marine turtle, and Young et al. (2024) have now completed the set with their study on flatback turtles from a healthy population located in northwest Australia. While these RIs were similar to those of other marine turtle species, differences in life history stage, sex, and location mean that species-specific data are needed. These data can be used to evaluate individuals in rehabilitation and for population health monitoring. If environmental changes are causing stress on flatback turtle populations, changes in RIs may provide rapid warning that intervention is needed; however, a periodic surveillance program may be needed for this to be useful.

## 4. FUTURE DIRECTIONS

In this section, we articulate some of the main outstanding research questions that should be addressed to build on information to enhance the management of flatback turtles. We note that this is not an exhaustive list of research needs for flatback turtles, but builds on recent research described here.

First, it is clear that future research on flatback turtles should draw heavily on the social sciences, specifically to answer remaining questions related to socio-economics and governance. For example, to build on Tuohy et al. (2024), more work is needed to understand how different stakeholder and actor groups understand and accept interventions, and there is a need for future research to understand indigenous perspectives (Butler et al. 2012). Further, van Putten et al. (2023) highlight the need to better understand how to most effectively share and exchange information with diverse communities about different interventions to build support for, and increase compliance with, such efforts. One approach showing promise in the recent literature for turtle conservation and management is that of visual framing (the way in which events are depicted, Ison et al. 2024), which could be explored further, among other options. Finally, both Tuohy et al. (2024) and van Putten et al. (2023) were conducted in communities highly dependent on industry (e.g. oil and gas, tourism), and further work is needed to better understand how such communities are willing to trade off between conservation and industrial development, so as to identify opportunities for successful co-location (Yates et al. 2015).

In addition to improving community engagement, there is a need to further understand how to weave and integrate different knowledge systems (i.e. scientific, experiential, community, and traditional knowledge) (Cornell et al. 2013) and incorporate that knowledge into decision-making processes. For example, and as shown by Ison et al. (2021), the successful conservation and management of flatback turtles is dependent on the coordination, cooperation, and collaboration of diverse stakeholders spanning government, non-government organisations, industry, scientific bodies, community groups, and indigenous groups, among others. Achieving this requires an understanding of the different social and organisational norms and practices of each actor/group and the relationships between them (e.g. to understand power and influence dynamics, van Putten et al. 2022). Co-production offers promise in this regard (Norström et al. 2020); however, further research is needed to understand how to operationalise co-productive practices in ways that are just and equitable (Muhl et al. 2023) and sufficiently agile to operate within a complex stakeholder environment (Chambers et al. 2022).

From a biological perspective, future research has 2 broad areas for expansion: (1) the development of knowledge on the post-hatchling and juvenile life stages and (2) understanding the variability vulnerability and adaptive capacity in relation to climate change and other pressures on the marine and terrestrial habitats. Unlike reef-associated or coastal species like green, hawksbill and loggerhead turtles, immature flatback turtles are challenging to find in the wild unless tagged (Peel et al. 2024). Hence, we have little knowledge of this life-history stage, which makes modelling, applying, and assessing interventions more difficult (Richards et al. 2024). Understanding diet, growth, and movement would enable more robust management of important foraging sites for the species, and some of these sites have been identified for flatback turtles (Abrantes et al. 2024, Peel et al. 2024). Climate change will present several pressures on flatback turtles across their range, especially as temperature rises. However, little is known about variability in vulnerability across the distinct stocks, thermal thresholds for embryo development, and sex determination across most of the species' range and potential site-specific mitigation options (but see Bentley et al. 2020). Given this uncertainty, a precautionary approach must be taken which includes consideration of future nesting sites south of current populations and testing of interventions with a long lead time.

While flatbacks survived sea-level rise at the end of the last ice age, the rate of current change and the additional human pressures are a cause for concern. Conservation interventions are now being widely considered for terrestrial and marine species, including turtles (Mason et al. 2021, Staines et al. 2023); however, most are applicable at local scales, or are still being tested for efficiency. Population models will continue to be an important tool to assess interventions, and ongoing monitoring across the range will be required to allow early detection of impacts on populations. It will be particularly important to assess the population outcome from cumulative impacts, as multiple threats exist in areas used by flatback turtles. Scenarios and adaptation pathways can play an important role in preparing robust plans, even where uncertainty exists. The collective set of tools illustrated in the Special 'Managing flatback turtles for the future' can be used widely in conservation, and we suggest that outcomes can be improved for many endangered and protected species.

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## LITERATURE CITED

Abrantes K, Wildermann N, Miller IB, Hamann M and others (2024) Intraspecific variability in flatback turtle habitat use: δ15N as an indicator of foraging locations. Endang Species Res 53:167–180

Alderman R, Hobday AJ (2017) Developing a climate adaptation strategy for vulnerable seabirds based on prioritisation of intervention options. Deep Sea Res II 140: 290–297

Bentley BP, Stubbs JL, Whiting SD, Mitchell NJ (2020) Variation in thermal traits describing sex determination and development in Western Australian sea turtle populations. Funct Ecol 34:2302–2314

Butler JR, Tawake A, Skewes T, Tawake L, McGrath V (2012) Integrating traditional ecological knowledge and fisheries management in the Torres Strait, Australia: the catalytic role of turtles and dugong as cultural keystone species. Ecol Soc 17:34

Chambers JM, Wyborn C, Klenk NL, Ryan M and others (2022) Co-productive agility and four collaborative pathways to sustainability transformations. Glob Environ Change 72:102422

Cornell S, Berkhout F, Tuinstra W, Tàbara JD and others (2013) Opening up knowledge systems for better responses to global environmental change. Environ Sci Pol 28:60–70

Department of Biodiversity, Conservation and Attractions (2017) North West Shelf Flatback Turtle Conservation Program Strategic Conservation Plan 2014–21. https://flatbacks.dbca.wa.gov.au/sites/default/files/2024-10/NWSFTCP%20Strategic%20Conservation%20Plan.pdf

Department of Environment and Science (2021) Queensland Marine Turtle Conservation Strategy (2021–2031) Queensland Government, Brisbane. https://nla.gov.au/nla.obj-3092690383/view

Duarte CM, Agusti S, Barbier E, Britten GL and others (2020) Rebuilding marine life. Nature 580:39–51
FitzSimmons NN, Pittard SD, McIntyre N, Jensen MP and others (2020) Phylogeography, genetic stocks, and conservation implications for an Australian endemic marine turtle. Aquat Cons: Mar Freshw Ecosyst 30:440–460
Fossette S, Loewenthal G, Peel LR, Vitenbergs A and others (2021) Using aerial photogrammetry to assess stock-wide marine turtle nesting distribution, abundance and cumulative exposure to industrial activity. Remote Sens 13:1116
Fuentes MM, Limpus C, Hamann M (2011) Vulnerability of sea turtle nesting grounds to climate change. Glob Change Biol 17:140–153
Fuentes MMBP, Santos AJB, Abreu-Grobois A, Briseño-Dueñas R and others (2024) Adaptation of sea turtles to climate warming: Will phenological responses be sufficient to counteract changes in reproductive output? Glob Change Biol 30:e16991
Gammon M, Fossette S, McGrath G, Mitchell N (2020) A systematic review of metabolic heat in sea turtle nests and methods to model its impact on hatching success. Front Ecol Evol 8:556379
Gammon M, Whiting S, Fossette S (2023) Vulnerability of sea turtle nesting sites to erosion and inundation: a decision support framework to maximize conservation. Ecosphere 14:e4529
Hobday AJ, Chambers LE, Arnould JPY (2015) Prioritizing climate change adaptation options for iconic marine species. Biol Conserv 24:3449–3468
Hobday AJ, van Putten EI, Cvitanovic C, Dunlop M and others (2024) Flatback futures — evaluating conservation interventions to reduce threats to an endemic Australian turtle. Endang Species Res 54:29–40
Hobday AJ, Dunlop M, Thomas L, v. Putten EI and others (2025) Flatback futures — scenarios and adaptation pathways for a marine turtle facing long-term change. Endang Species Res 56:69–91
Hounslow JL, Jewell OJD, Fossette S, Whiting S and others (2021) Animal-borne video from a sea turtle reveals novel anti- predator behaviors. Ecology 102:e03251
Ison S, Pecl G, Hobday AJ, Cvitanovic C, van Putten I (2021) Stakeholder influence and relationships inform engagement strategies in marine conservation. Ecosyst People (Abingdon) 17:320–341
Ison S, Cvitanovic C, Pecl G, Hobday AJ, van Putten I (2024) The role of visual framing in marine conservation communication. Ocean Coast Manage 248:106938
Jensen MP, Allen CD, Eguchi T, Bell IP and others (2018) Environmental warming and feminization of one of the largest sea turtle populations in the world. Curr Biol 28: 154–159
Jouffray JB, Blasiak R, Norström AV, Österblom H, Nyström M (2020) The blue acceleration: the trajectory of human expansion into the ocean. One Earth 2:43–54
Kamrowski RL, Limpus C, Pendoley K, Hamann M (2015) Influence of industrial light pollution on the sea-finding behaviour of flatback turtle hatchlings. Wildl Res 41: 421–434
Kaplan IC (2005) A risk assessment for Pacific leatherback turtles (*Dermochelys coriacea*). Can J Fish Aquat Sci 62: 1710–1719
King J, Whiting SD, Adams PJ, Bateman PW, Fleming PA (2023) Camera traps show foxes are the major predator of flatback turtle nests at the most important mainland western Australian rookery. Wildl Res 51:WR22109
Laloë JO, Hays GC (2023) Can a present-day thermal niche be preserved in a warming climate by a shift in phenology? A case study with sea turtles. R Soc Open Sci 10: 221002
Laubenstein T, Smith TF, Hobday AJ, Pecl GT, Evans K, Fulton EA, O'Donnell T (2023) Threats to Australia's oceans and coasts: a systematic review. Ocean Coast Manage 231:106331
Mason C, Hobday AJ, Alderman R, Lea MA (2021) Climate adaptation interventions for iconic fauna. Conserv Sci Pract 3:e434
Merrie A, Dunn DC, Metian M, Boustany AM and others (2014) An ocean of surprises — trends in human use, unexpected dynamics and governance challenges in areas beyond national jurisdiction. Glob Environ Change 27:19–31
Muhl EK, Armitage D, Anderson K, Boyko C and others (2023) Transitioning toward 'deep' knowledge co-production in coastal and marine systems: examining the interplay among governance, power, and knowledge. Ecol Soc 28(4):17
Nash KL, Cvitanovic C, Fulton EA, Halpern BS, Milner-Gulland EJ, Watson RA, Blanchard JL (2017) Planetary boundaries for a blue planet. Nat Ecol Evol 1:1625–1634
Norström AV, Cvitanovic C, Löf MF, West S and others (2020) Principles for knowledge co-production in sustainability research. Nat Sustain 3:182–190
Peel LR, Whiting SD, Pendoley K, Whittock PA and others (2024) I still call Australia home: Satellite telemetry informs the protection of flatback turtles in Western Australian waters. Ecosphere 15:e4847
Poiner IR, Harris ANM (1996) Incidental capture, direct mortality and delayed mortality of sea turtles in Australia's northern prawn fishery. Mar Biol 125:813–825
Poloczanska ES, Limpus CJ, Hays GC (2009) Vulnerability of marine turtles to climate change. Adv Mar Biol 56: 151–211
Pritchard AM, Sanchez CL, Bunbury N, Burt AJ and others (2022) Green turtle population recovery at Aldabra Atoll continues after 50 yr of protection. Endang Species Res 47:205–215
Putman NF, Hawkins J, Gallaway BJ (2020) Managing fisheries in a world with more sea turtles. Proc R Soc B 287: 20200220
Richards SA, Cvitanovic C, Dunlop M, Fossette S and others (2024) Identifying impactful sea turtle conservation strategies: a mismatch between most influential and most readily manageable life-stages. Endang Species Res 54: 15–27
Smith CE, Booth DT, Crosby A, Miller JD, Staines MN, Versace H, Madden-Hof CA (2021) Trialling seawater irrigation to combat the high nest temperature feminisation of green turtle *Chelonia mydas* hatchlings. Mar Ecol Prog Ser 667:177–190
Smithers SG, Dawson JL (2023) Beach reprofiling to improve reproductive output at the world's largest remaining green turtle rookery: Raine Island, northern Great Barrier Reef. Ocean Coast Manage 231:106385
Staines MN, Versace H, Laloë JO, Smith CE and others (2023) Short-term resilience to climate-induced temperature increases for equatorial sea turtle populations. Glob Change Biol 29:6546–6557
Tuohy P, Richards SA, Cvitanovic C, van Putten I, Hobday AJ, Thomas L, Annand-Jones R (2024) Social acceptability of conservation interventions for flatback turtles:

comparing expert and public perceptions. Endang Species Res 53:1–12
Turner Tomaszewicz CN, Avens L, Seminoff JA, Limpus CJ and others (2022) Age-specific growth and maturity estimates for the flatback sea turtle (*Natator depressus*) by skeletochronology. PLOS ONE 17:e0271048
van Putten I, Ison S, Cvitanovic C, Hobday AJ, Thomas L (2022) Who has influence? The role of trust and communication in the conservation of flatback turtles in Western Australia. Reg Stud Mar Sci 49:102080
van Putten IE, Cvitanovic C, Tuohy P, Annand-Jones R and others (2023) for a focus on flatback turtles: the social acceptability of conservation interventions in two Australian case studies. Endang Species Res 52:189–201
Whiting AU, Thomson A, Chaloupka M, Limpus CJ (2008) Seasonality, abundance and breeding biology of one of the largest populations of nesting flatback turtles, *Natator depressus*: Cape Domett, Western Australia. Aust J Zool 56:297–303
Whittock PA, Pendoley KL, Hamann M (2014) Inter-nesting distribution of flatback turtles *Natator depressus* and industrial development in Western Australia. Endang Species Res 26:25–38
Whittock PA, Pendoley KL, Larsen R, Hamann M (2017) Effects of a dredging operation on the movement and dive behaviour of marine turtles during breeding. Biol Conserv 206:190–200
Wilcox C, Puckridge M, Schuyler QA, Townsend K, Hardesty BD (2018) A quantitative analysis linking sea turtle mortality and plastic debris ingestion. Sci Rep 8: 12536
Wilson P, Thums M, Pattiaratchi C, Whiting S, Pendoley K, Ferreira LC, Meekan M (2019) High predation of marine turtle hatchlings near a coastal jetty. Biol Conserv 236: 571–579
Wilson P, Pattiaratchi C, Whiting S, Ferreira LC, Fossette S, Pendoley K, Thums M (2023) Predicting core areas of flatback turtle hatchlings and potential exposure to threats. Endang Species Res 52:129–147
Yates KL, Schoeman DS, Klein CJ (2015) Ocean zoning for conservation, fisheries and marine renewable energy: assessing trade-offs and co-location opportunities. J Environ Manage 152:201–209
Young LR, Booth DT, Smith CE, Madden Hof CA (2023) Seawater irrigation on nests can increase male marine turtle production. Mar Ecol Prog Ser 718:85–97
Young EJ, Warren KS, Whiting SD, Stephens NS and others (2024) Haematologic and plasma biochemical reference intervals for flatback turtles *Natator depressus.* Endang Species Res 53:181–198

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