The role of vegetated coastal wetlands for marine megafauna conservation

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Highlights

Marine megafauna and vegetated coastal wetland habitats – seagrasses, saltmarshes and mangroves – are under intense threat and declining globally.

Emerging research and novel methodologies have unveiled important, previously-unknown habitat associations between marine megafauna and these habitats.

Unless we can conceptualize and critically examine these habitat associations, management and conservation can be undermined.

Identifying threatened species that are dependent on threatened habitats is essential for informing on actions to prevent population declines.

16 **Abstract**

17 Habitat loss is accelerating a global extinction crisis. Conservation requires understanding
18 links between species and habitats. Emerging research is revealing important associations
19 between vegetated coastal wetlands and marine megafauna such as cetaceans, sea turtles and
20 sharks, but these links have not been reviewed and the importance of these globally declining
21 habitats is undervalued. We identify associations for 102 marine megafauna species that
22 utilize these habitats, increasing the number of species with associations based on current
23 IUCN species assessments by 59% to 174 , accounting for over 13% of all marine
24 megafauna. We conclude that coastal wetlands require greater protection to support marine
25 megafauna, and present a simple, effective framework to improve inclusion of habitat
26 associations within species assessments.

27 **Main Text**

28 **Are vegetated coastal wetlands important for marine megafauna?**

29 Marine **megafauna** (see Glossary) are globally recognized as providing significant economic,
30 cultural and ecological values [1, 2]. Despite this, many have experienced population declines
31 putting some species at risk of extinction [3-5]. Emerging research and novel methodologies
32 are finding important, previously-unknown habitat associations between marine megafauna
33 and **vegetated coastal wetlands** – seagrasses, mangroves and saltmarshes – [e.g. 6, 7],
34 suggesting that these marine habitats are important in supporting and sustaining megafauna.
35 However, vegetated coastal wetlands are also in global decline and there is an urgent need for
36 effective management and conservation effort in these habitats [8-11]. The ability to
37 implement management and conservation in marine systems is, however, often impeded by
38 incomplete understanding of species habitat requirements and critical ecological processes
39 operating between species and habitats [12]. While coastal regions in general have been
40 suggested as areas of conservation concern for marine megafauna [4, 13], the importance of
41 seagrasses, mangroves and saltmarshes specifically is not currently well conceptualized for
42 megafauna or their conservation.

43 Megafauna also fulfil important functions for coastal wetlands. Semi-aquatic species link
44 aquatic and terrestrial biomes by transporting nutrients across boundaries [14], while
45 migratory species with large home ranges can disperse nutrients and plant propagules across
46 wide areas [15-17]. Grazing of seagrass by turtles and dugongs can benefit seagrass
47 communities by increasing nitrogen availability [18], and suggests that declines of these
48 species have the potential to cause degradation of seagrass meadows [19]. Megafauna
49 predators such as sharks also assist in maintaining and growing reserves of ‘blue carbon’

within coastal wetland habitats [20] and play important roles as apex predators in near shore food webs [21].

To advance the global state of knowledge surrounding links between these coastal wetland habitats and marine megafauna, we systematically classify habitat associations from the published literature (see Appendix A for methodology). Given the increasing global importance and use of the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species database [22], we also critically evaluate species assessments for megafauna considered to have an association with coastal wetlands and propose an updated framework for the inclusion of habitat data in assessments. It is timely that we review this literature to identify priorities for wetland research and evaluate how wetland protection can best serve megafauna.

Identifying and defining habitat associations

Species conservation and protection, and the policy that enables these, relies on knowledge of how and which species utilize specific habitats. The standardization of habitat associations within IUCN species assessments also allows geographical and taxonomic comparisons to be made that are important for guiding conservation efforts and assessing conservation outcomes [23]. Inaccurate or missing information can compromise these efforts. For example, the often-cited statement that "an estimated 75% of commercially caught fish depend directly on mangroves" [24] was recently determined to be wildly inaccurate and not based on definitive scientific evidence. The use of unsupported claims poses serious issues for conservation as hypotheses and arguments that are built upon it are weakened by the lack of scientific evidence and can be easily be debunked [24].

Here, we classify habitat associations from the literature as: (i) *Occurrence* – occurring within or directly adjacent to the habitat (e.g. GPS tracking of turtles within seagrass patches,

observing dolphins along mangrove banks); (ii) *Grazing* – directly consuming the habitat forming species (e.g. observing dugongs, *Dugong dugon*, consuming seagrass, turtle stomach lavage samples containing mangrove fruits); (iii) *Foraging* – hunting or scavenging within or directly adjacent to the habitat (e.g. rays foraging on invertebrates within seagrass meadows, sharks hunting along the edges of seagrass meadows), or from the habitat’s food web (e.g. isotopic analyses identifying seagrass-associated prey forming part of the diet), and; (iv) *Breeding* – breeding occurring within the habitat or juveniles within sites that satisfy the requirements of a nursery habitat [25] (e.g. juvenile lemon sharks, *Negaprion brevirostris*, congregating within mangrove-fringed lagoons). We include ‘directly adjacent to the habitat’ as megafauna can, for example, hunt prey along mangrove-fringed shorelines without physically entering the small gaps within mangrove roots (although they can be above aerial roots without this being mentioned within studies).

Occurrence is considered an **indirect association** and the other classifications are **direct associations**. Direct habitat-associations have varying strengths of evidence. That is, levels of **habitat dependency** are subject to gradation. For example, the level of dependency for sharks using mangrove-fringed lagoons as nursery areas is less clear than for dugongs consuming seagrass. It may be that the mangroves provide specific protection and prey resources, and are irreplaceable, but it may also be that sharks would just as readily and successfully use the lagoon as a nursery if a different vegetation type was present. Ideally, these classifications would feed into a quantitative assessment of how the habitat contributes to a species population growth rate, and thus how habitat decline can increase the risk of extinction. Such quantitative assessments would require estimating differences in population demographic rates between locations or times with and without the habitat [26]. This can be relatively straightforward for species that are solely reliant on one food type (i.e. dugongs

consuming seagrass), but very difficult for species that have a facultative dependence on the habitat.

Although our separation of habitat associations into direct and indirect provides an easy and informative means to assess habitat associations, we might also be over estimating the importance of coastal wetlands for some species, because evidence of associations from these habitats might be an artefact of the surrounds or adjacent alternative habitats rather than the habitat forming species itself [e.g. mangroves; 27]. Conversely, we might be dismissing key habitat associations as indirect due to a lack of supporting scientific data. For example, turtles can rest and find refuge amongst mangroves and crocodiles use saltmarsh to bask, and these could be vital ecological functions provided by vegetated coastal wetlands, but under our criteria are deemed as an *occurrence*. Hence, our occurrence data could be considered knowledge gaps, where data is still required to properly assess habitat association types.

Megafauna associations with vegetated coastal wetlands

Our review of 341 studies (Appendix B) identified 102 megafauna species associated with coastal wetlands (Appendix C). Associations were most commonly documented by visual observation (55%), electronic tracking (14%), or from dietary analysis based on gut contents (18%) or **stable isotopes** (11%). Less common methods (2%) included acoustic recordings, contaminant and fatty acid levels, and animal-borne video cameras. Many species had well-studied and important associations with coastal habitats (Figure 1). For example, seagrass is often the only dietary component for green turtles (*Chelonia mydas*) and dugongs [28, 29], and this was well conceptualized and validated in the literature. Similarly, mangroves, saltmarshes and seagrasses offer ideal hunting and foraging grounds for predators such as dolphins, sharks, rays, and crocodiles [30-32]. These habitats also function as nurseries where

juveniles of species such as critically endangered smalltooth sawfish [*Pristis pectinata*; 33], dugongs [34] and lemon sharks [35] seek refuge during vulnerable early life-stages.

Sharks and rays were the dominant taxonomic group, contributing 66 of the 102 species from our literature review. This group was primarily associated with seagrass and mangroves, with most direct associations related to hunting within seagrass patches (18 species; Appendix D). Few megafauna were linked with saltmarsh (12 species), indicating that this habitat is relatively less important for megafauna or that it is less well studied. Overall, the most studied species in terms of number of studies identifying links with were the bonnethead shark (*Sphyrna tiburo*), the lemon shark, and the smalltooth sawfish.

Of the 102 species identified from the peer-reviewed literature, 64 did not have any of the three habitat types recognized as a habitat within their IUCN assessment. Conversely, we identified 71 species with noted coastal wetland habitat associations from IUCN Red List assessments that were not identified in our search of the published literature. Evidence for IUCN associations were largely based on unpublished literature, personal observation, personal communication, and assumptions that the species would occur in the same habitat as congeneric species. In total, these 64 species increase the number of marine megafauna with known habitat associations with coastal wetlands by 59%, to 174 species (Figure 2). This considerable increase means that at least 13% of all extant marine megafauna species have some link with coastal wetlands (Figure 2).

The importance of habitat associations in assessments

IUCN Red Lists have become a go-to source of information used to guide species conservation [36, 37]. The wealth of additional data collected during the assessment process, such as threats and habitat associations, is regarded as one of its most important features, insofar that these parameters are standardized to allow comparative analyses [38]. These can

be used, for example, to compare trends for suites of species in different habitats. Red List threat categorizations also provide a baseline for measuring conservation responses [22]. For instance, conservation recommendations identified in assessments for globally threatened birds in 2000 resulted in two-thirds of threatened bird species having some of these actions implemented by 2004 [22, 39]. Habitat-based conservation actions are often recommended in Red List assessments for those species with strong habitat associations [22].

Despite important habitat associations identified in our literature review, IUCN assessments for 64 of the 102 species did not include any vegetated coastal wetland habitat (even though 32 species had direct associations). For example, green turtles (*Chelonia mydas*) often rest in mangroves and consume mangrove leaves and fruits [40-43], and bull sharks have strong links with mangrove estuaries as nurseries [26], yet mangroves are not currently identified as important for these species. In some cases, such as for many of the crocodiles and alligators, assessments are largely incomplete and were conducted prior to the studies that identified and published evidence of important habitat associations (Appendix C). Different forms of information are used to inform species conservation, such as expert knowledge and species distribution models. The information within IUCN assessments is also used to identify actions for threatened species management. Therefore, when species assessments overlook habitat associations, as we show currently occurs for 64% of the species identified, conservation may not be directed towards the most effective management actions such as protecting habitats.

A framework for the inclusion of habitat data in species assessments

We argue that greater consideration of the role that vegetated coastal wetlands have in the lives of many megafauna should be included in management and conservation plans for these species. Otherwise, valuable resources might be invested in ineffective conservation action

that does not halt species decline. This is particularly important as almost half of these species are listed as threatened (Figure 3). Although IUCN assessments provide the opportunity to apply a ranking of habitat importance (e.g. ‘suitability’ and ‘major importance?’), these are seldom included in assessments, are difficult to interpret, and do not offer the capacity to contrast direct or indirect habitat-associations.

Habitat associations are important information which should be included in assessments as a priority whenever possible. At minimum, objective classification of the direct or indirect nature of each association for each habitat-type should be articulated and supported by clear evidence. Ideally, we would also identify how reliant a species is on a habitat by estimating levels of dependency (e.g. **obligate habitat-use**). Therefore, assessments would include: (i) all habitat types the species is known to associate with; (ii) the association-type broadly categorised into occurrence, grazing, foraging or breeding (or other relevant species-specific categories); (iii) where the evidence supporting this association comes from, and; (iv) some estimate of the level of habitat dependence. This provides transparent and useful information for achieving the many goals of the IUCN Red List, such as identifying knowledge gaps, guiding conservation research efforts, informing policy and conventions, and improving conservation planning and decision-making (see: <http://www.iucnredlist.org/about/uses>). Finally, many assessments should be updated as new information about habitat associations is published in the scientific literature. We acknowledge the considerable time and effort required to achieve these recommendations but argue that the benefit would significantly outweigh the time cost.

Bringing habitat loss and degradation in vegetated coastal wetlands to the fore

Correctly identifying habitat associations will better inform impact assessments for habitat loss and degradation. These threats are prolific in coastal wetlands [44] and have significant

effects on marine megafauna (Box 1). However, when threat data were presented for the species associated with these habitats, 52% of the IUCN species assessments did not mention any form of human-induced habitat change. The effects of habitat change can be overlooked for marine animals [45] because of the sub-lethal, chronic effects that occur initially, and because impacts can be hard to directly attribute to species declines without long-term datasets separating natural fluctuations from the effects of human impacts [46].

This is particularly true for sharks and rays, the largest group of species without habitat change listed as a threat. For this group, fisheries pressures, which are comparatively more straightforward to quantify and interpret, were often listed as a threat. It is important, though, that we assess and quantify relationships between megafaunal demography and changes in coastal wetlands for those species with known habitat associations. This is especially true for the persistence of harvested megafauna (i.e. fisheries species) with critical life history links to threatened habitats, because under this scenario, fishery management alone may be insufficient to prevent population declines [45]. In this case, incorporating habitat change into conservation assessments and management plans could be achieved by recognizing the importance of vegetated coastal wetlands to marine megafauna and conducting robust research into the habitat associations that exist. This will not only assist in the protection of the economically and ecologically important megafauna, but also the numerous co-benefits to humans (including many ecosystem services) provided by vegetated coastal wetland [47, 48].

Existing and emerging techniques

Much can be done to address gaps between species conservation and habitat change, and future research would do well to further utilize both existing and emerging technologies. Recent advances in **remote sensing** have enabled the development of spatially explicit, high-resolution global datasets on the distribution of, and rates of change in, ecosystems

and habitats [Box 2; 49]. Coupled with modern computing capacity and analytical tools, models and predictions of how habitat change alters species occurrence, distributions and extinction probability [38, 50] can be made if robust information about habitat-associations along with the strength and importance of these associations is known. This information directly feeds into species assessments and spatially explicit species conservation, improving outcomes [51, 52]. Although this level of knowledge remains elusive for many taxa, advances in commonly used techniques such as **telemetry**, capture-mark-recapture, video (stationary and animal-borne), and stable isotope analyses are providing valuable insight into these associations [7, 53]. For example, isotope analysis recently revealed the bonnethead shark as the first truly omnivorous shark which eats, digests and assimilates seagrass material [6]; an insight that could not have been achieved from telemetry alone. Ultimately, applying combinations of existing and emerging techniques can provide new information that is vital for assessing the vulnerability of coastal ecosystems (and the species within them) to abrupt habitat loss and degradation [54].

We envisage two ways new data-sets could facilitate updating listings of threatened species to account for loss of and change in coastal wetlands. First, trends in habitats can be incorporated into the threat assessments in a qualitative way, so that habitat loss is recognized as a key threatening process in a greater number of assessments. This facilitates conservation agencies to direct species-specific funding toward habitat protection and restoration as a way of preventing extinction. Second, data on the demographic responses of megafauna to wetland loss are needed for models that can be used to quantitatively assess extinction risk. Quantitative assessments are a crucial aspect of prioritizing limited conservation funds between different actions [55], such as habitat protection versus bycatch mitigation, and telemetry data can be used to study behavioural and demographic responses to habitat change, such as changes in mortality [e.g. 26].

Caveats and limitations

We focused our review on the three major vegetated coastal wetland habitats – seagrasses, mangroves, and saltmarshes – as defined by the Ramsar Convention (see Glossary for Ramsar definition). While other coastal habitats are undoubtedly also important for marine megafauna (e.g. tidal mudflats and inshore coral reefs), we limited our search to these three wetland habitats due to their similarities (conspicuous structural angiosperm vegetation), to ongoing global declines in these habitats, and direct links as diet items for vulnerable marine megafauna taxa. Furthermore, areas of offshore seagrasses do exist. Due to the lack of a strict definition of coastal and the fact that most seagrasses are nearshore, we included all associations with seagrass in our review. It is therefore possible that some of the associations identified here come from areas that could be considered non-coastal. Although this means that some species – likely to only be sharks or rays – might not be using strictly coastal seagrasses, their inclusion would not change the conclusions of this review. Even species regarded as truly open-ocean, such as the Giant manta ray, *Manta birostris*, have been observed swimming over coastal seagrasses in 1.5 m of water [56], highlighting again that associations span a broad continuum of strengths.

Although grey literature can be a useful source of information used in IUCN assessments, we focussed on peer-reviewed studies that were able to provide evidence for specific associations partly under the assumption that a peer-review process is preferred before data should be used to develop hypotheses or incorporated into broader studies. Peer-review is, thus, a gold standard for quality control of science and a standard for reviews because it provides systematic criteria for searching the literature. Finally, our discussion on the impacts of habitat loss to marine megafauna likely underestimates the magnitude of the problem. For instance, it is likely that a significant number of megafauna not identified here would also be

affected by losses in seagrasses, mangroves or saltmarshes, or the species they support, due to cascading effects on water quality, food webs, and links between coastal wetlands and other habitat types [23, 57].

Concluding Remarks and Future Perspectives

Vegetated coastal wetlands are among the most biologically productive ecosystems on earth. Our review identifies key habitat associations between marine megafauna and coastal wetlands, highlighting: (i) the importance of these habitats in the lives and conservation of these species; (ii) the need for greater recognition of habitat change as a potential driver of megafauna decline; (iii) the need to update and improve IUCN species assessments to align them with current knowledge; (iv) global hotspots of concern where coastal wetland loss and marine megafauna biodiversity intersect (Box 2), and; (v) how existing and emerging techniques can be used in concert to better quantify habitat associations and dependencies.

At present, the importance of coastal habitats to marine megafauna is greatly undervalued, perhaps because there is no review of these habitat-associations and low acknowledgment of the importance of vegetated coastal wetlands to megafauna in species assessments. We found a considerable proportion (13%) of marine megafauna have some link with seagrasses, mangroves or saltmarshes, with some species exhibiting important, largely obligate habitat associations. A greater appreciation of the role of these habitats for marine megafauna should, thus, be considered when estimating species extinction likelihoods. Our simple yet effective framework for the inclusion of habitat data in IUCN assessments is a starting point for better conceptualizing habitat within assessments. Future research should utilize emerging methods and technologies to strengthen our understanding of the importance of habitat for marine species and aim to quantify levels of habitat dependency rather than just noting associations. We conducted this review to highlight the importance of vegetated coastal

290 wetlands to marine megafauna and spur interest in further describing these associations (see
291 Outstanding Questions), representing a timely advancement towards improving management
292 and conservation outcomes for these important and iconic animals.

293

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458

Figure Captions

Figure 1. Marine megafauna habitat associations with vegetated coastal wetlands – seagrasses, mangroves and saltmarshes – confirmed in the peer-reviewed scientific literature. Marine megafauna graze, forage and breed in all three habitats, as indicated by symbols within the habitat-association matrix. We classify habitat-associations from the literature as: (i) *Occur* – within or directly adjacent to the habitat; (ii) *Graze* – directly consuming the habitat forming species; (iii) *Forage* – hunting or scavenging within or directly adjacent to the habitat, or from the habitat’s food web, and; (iv) *Breed* – juveniles within sites that satisfy the requirements of a nursery habitat or nesting within the habitat. Photo credits: all images are Creative Commons (CC) or Public Domain (PD). Sea turtles – P. Lindgren (CC BY-SA 3.0); Dugongs and manatees – J. Willem (CC BY-SA 3.0); Dolphins and porpoises – Z. Alom (PD); Sharks and rays – A. Kok (CC BY-SA 3.0); Crocodiles and alligators – Mattstone911 (CC BY-SA 3.0); Otters, seals and minks – L. K. Yap (CC BY-SA 2.0). Original images have been cropped.

Figure 2. Summary statistics from reviewing the literature and the International Union for the Conservation of Nature database. The number of species identified as having a habitat association with seagrass, mangroves or saltmarsh based on IUCN species assessments (blue bars) and those additional species from our literature review (purple bars). The resultant percentage increase in the number of species with known habitat associations (Increase %) and the proportion of all species within key taxonomic groups that are associated with coastal wetlands (Proportion species %) are shown. Our literature review considerably increases the number of species with known habitat-associations based on habitat data extracted from IUCN species assessments, potentially compromising

conservation efforts given the global rates of decline in seagrasses, mangroves and saltmarshes.

Figure 3. Vegetated coastal wetland-associated marine megafauna IUCN threat status.

The percentage of species within key taxonomic groups as classified by the International Union for the Conservation of Nature (IUCN) Red List of Threatened species categories. More than 50% of species are near threatened or worse, highlighting the critical need for conservation action for these animals and their habitats. Maskrays have been excluded from this figure as no status was assigned.

Box 1. The impact of vegetated coastal wetland loss and degradation on marine megafauna

Reductions in the extent and condition of seagrasses, mangroves and saltmarshes can impact marine megafauna by: (i) reducing the quantity and quality of food for herbivores; (ii) depleting prey availability for predators and scavengers; (iii) disrupting key life-history stages by limiting the availability or effectiveness of nursery and refuge areas; (iv) reducing the amount of suitable breeding habitat; (v) increasing inter-patch distance and reducing habitat connectivity, and; (vi) increasing species interactions with other human stressors.

Furthermore, the causal factors of habitat loss and degradation also affect megafauna directly [e.g. pollution, warming seas, fishing pressures, exotic species introductions; 58, 59, 60].

Habitat loss and degradation of coastal wetlands can impact marine megafauna through complex multi-stressor interactions. For example, increased fragmentation or decreased quality of seagrass beds forces herbivores to travel farther to find high-quality food patches to fulfil their daily energy requirements [61]. Doing so can increase the risk of boat strikes, a leading causes of mortality [62, 63]. We could infer that by reducing the causes of seagrass fragmentation and degradation (e.g. improving water quality or minimizing coastal development), seagrass beds would become denser and more connected, which would serendipitously reduce the risk of boat strikes. The benefit of actions on habitat quality, thus, has an additional, but largely unidentified, benefit in terms of reducing boat mortalities. Ultimately, saving habitat and protecting remaining habitat from other stressors (e.g. boat no-go zones) could be the ‘silver bullet’ for conservation of marine megafauna.

Furthermore, threatening processes are also context dependent, where localized threats, such as the construction of a port or nutrient discharge from a heavily urbanized estuary can disproportionately affect species with lower capacity to move away from the threat. On the

515 other hand, far-ranging species such as dugongs that aren't necessarily dependent on specific
516 habitat patches for food will generally be less affected by localized declines [64]. This
517 contrasts to many far-ranging, migratory terrestrial species that do rely on specific coastal
518 wetlands as breeding grounds, where localized habitat loss and degradation can cause
519 significant population declines [e.g. migratory birds breeding in saltmarsh habitats; 65]. This
520 highlights several important considerations when designing conservation and management
521 initiatives for marine megafauna. Irrespective of terrestrial or aquatic origin, or life-history
522 strategies, when threats occur over large geographical areas, such as those due to human-
523 induced climate change, the impact of habitat loss and degradation are likely to affect a large
524 number of species [66].

Box 2. Global biodiversity of vegetated coastal wetland-associated marine megafauna and hotspots of conservation concern

Coastal wetland-associated megafauna biodiversity was highest in Southeast Asia, northern Australia, the east and west coasts of Africa, the southern United States, Central America and northern South America (Figure I). Conservation outcomes can be improved and made more efficient by identifying hotspots where high concentrations of threatened native species intersect with habitats that are being lost and degraded [67]. High rates of mangrove loss intersected with threatened megafauna distributions most strongly in Southeast Asia, Florida (USA), Mexico, and northern Brazil (Figure I). Southeast Asia is the largest mangrove-holding region of the world, and mangroves are being lost at rates far exceeding global averages [68], largely due to aquaculture and agriculture [69]. Brazil and Mexico are also mangrove-rich countries [68] and guiding protection and restoration of mangroves towards these hotspots will assist in the conservation of threatened marine megafauna that utilize these important habitats.

Figure I. Vegetated coastal wetland-associated marine megafauna distributions across three key geographical regions. Heatmaps of biodiversity for 172 of the 174 marine megafauna identified as having an association with seagrasses, mangroves and saltmarshes for the three geographical regions with the most species (to aid visualization; A: Asia Pacific; B: Africa and Europe; C: North and South America). The blue dots represent locations of field studies from the literature review, and the graded colours represent species richness (see Key). Note that the distributions of some species (e.g. otters and caiman) extend far inland, into freshwater creeks and rivers. The number of species that are listed as threatened under IUCN and directly associated with mangroves from our literature search (13 species) with distributions that intersect with high rates of mangrove loss (D – F). Mangrove loss (2000-

549 2012) was calculated for all $0.2^\circ \times 0.2^\circ$ cells using data from Hamilton and Casey [68], and
550 we show only cells within the top 10th percentile for cells that experienced some loss over
551 this time (i.e. cells with no change or increases were excluded prior to percentile calculation).
552 See Appendix A for mapping methodology and Appendix E for full global maps.

553 **Glossary**

554 **Direct associations** – A habitat association where the animal directly utilizes the habitat as a
555 food source, foraging ground, nursery, breeding area, or some other interaction beyond
556 simply occurring within a habitat.

557 **Ecosystem engineers** – An ‘ecosystem engineer’ is any organism that creates, significantly
558 modifies, maintains or destroys a habitat.

559 **Habitat dependency** – The quantitative measure of how reliant an animal is to a specific
560 habitat type (e.g. obligate habitat-use).

561 **Indirect association** – A habitat association with no evidence of a direct association (e.g.
562 occurrence).

563 **Marine megafauna** – Primarily aquatic species from the following groups: sea turtles,
564 whales, dolphins, porpoises, otters, minks, seals, crocodiles, alligators, dugongs, manatees,
565 and sharks and rays (elasmobranchs).

566 **Obligate habitat-use** – When a specific habitat type is fundamentally needed for an animal’s
567 existence.

568 **Remote sensing** – The scanning of the earth by satellite or high-flying aircraft to obtain
569 information about it, particularly in terms of habitat and vegetation mapping.

570 **Stable isotopes** – Non-radioactive forms of atoms that can be used as indicators to trace the
571 diet and habitat used by animals prior to the sampling period.

572 **Telemetry** – The process of recording and transmitting the readings of an instrument, often
573 used to track animal movements.

574 **Vegetated coastal wetlands** – the three key vegetated coastal wetland habitats – seagrass,
575 saltmarsh and mangrove – as defined by the Ramsar Convention (wetland categories B, H
576 and I, respectively): ‘wetlands include a wide variety of inland habitats such as marshes,
577 peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves,
578 intertidal mudflats and seagrass beds, and also coral reefs and other marine areas no
579 deeper than six metres at low tide, as well as human-made wetlands such as dams,
580 reservoirs, rice paddies and wastewater treatment ponds and lagoons’ [70].

Outstanding Questions

Given that the links between megafauna and vegetated coastal wetlands are more widespread than was known, how can this nexus be used to support protection and restoration of coastal wetlands, and will more accurate information about dependencies help?

How can information on habitat associations within IUCN and other species assessments facilitate on-ground initiatives to conserve and protect coastal wetlands and megafauna?

How do changes in coastal wetlands affect demographic rates and extinction risk of marine megafauna that use wetlands in different ways such as feeding and reproduction?

Figure 1

Figure 2

Figure 3

Figure I (Box 2)

Appendix A

Literature search

We performed a literature search on 8th August 2018 using ISI Web of Science, Scopus and Google Scholar (first 200 results), and the search string: (mangrove* OR “salt marsh” OR “saltmarsh” OR “tidal marsh” OR seagrass* OR “coastal wetland*” OR “manatee grass” OR “turtle grass” OR cordgrass OR shoalgrass OR eelgrass OR *Spartina*) AND (megafauna* OR turtle* OR cetacean* OR dolphin* OR porpoise* OR whale* OR seal* OR “sea lion*” OR “sea mink*” OR manatee* OR dugong* OR otter* OR “sea cow*” OR crocod* OR alligator* OR caimen OR shark* OR *ray OR elasmobranch* OR sawfish*). We also examined the reference lists of selected studies, including related reviews. Excluding duplicates, we were left with a pool of 3448 potentially relevant studies. We subsequently conducted targeted literature searches using genus and species names, and IUCN species lists to be as comprehensive as possible. This resulted in an additional 39 useful papers.

Data extraction and classification

To be included, a study had to have published data identifying an implicit or explicit habitat association between marine megafauna (mammals, reptiles and elasmobranchs; see search term for included taxa) and vegetated coastal wetlands (specifically mangroves, saltmarsh or seagrass meadows). A range of metadata was extracted from each study where possible, including: location (continent, country, co-ordinates), year of study, habitat type, species taxonomy, life-history stage, habitat association (e.g. feeding), method used (e.g. visual survey) and whether the association was a direct or indirect link to the habitat.

Studies that assumed foraging had occurred without evidence such as dugong feeding tracks or turtle bite marks on seagrass, were not included. Studies did not have to explicitly state an

association between megafauna and coastal wetlands to be included. For example, a study that discussed capturing turtles over seagrass beds that were later used for some other purpose were included. This association would be defined as ‘occurrence’, ‘visual’, and ‘indirect’, for association type, method, and whether the link to the habitat was direct or indirect, respectively.

We included crocodiles, alligators and otters – which we considered to be largely aquatic species – but excluded terrapins and waterbirds. Throughout science, the definition of megafauna has included numerous combinations of taxonomic groups dependent on the scope of the study, and we feel our decisions are valid for this study’s purpose and are explicitly highlighted in the Glossary. We extracted information from 340 studies. See Appendix C for a bibliography of the included studies.

Megafauna distribution map

Species distributions ($n = 172$) were downloaded from individual IUCN species assessments where available, and were merged into a single layer using ArcGIS. We dissolved the layers to achieve one single polygon per species. We used spatial joins to calculate the number of species that occupied each $450 \text{ km} \times 450 \text{ km}$ grid cell to create a heatmap of biodiversity using the Mercator projection from WGS1984. We then added points representing the sites for which associations were noted from our literature review.

Mangrove loss intersecting with megafauna biodiversity

Using data from Hamilton and Casey [1], a vector layer consisting of $0.2^\circ \times 0.2^\circ$ cells was generated for 2000 and 2012 and each cell was defined as a “landscape”. Each landscape was queried to identify if mangroves were present within the borders; if mangroves were not detected the cell was removed. The geographic extent of cells which had mangroves present

was then used to crop the raster images. Once the image was cropped to the appropriate extent the image was transformed into a binary landscape. Any cell with mangrove density greater than zero was defined as mangrove. This threshold was chosen because the dataset utilised does not have inter-annual variability within cells, with the exception of a cell losing all mangroves present (>0 to 0). Rasters were then spatially transformed to a local UTM and exported as GeoTIFF files, resulting in 8,985 landscapes with mangrove presence in 2000. We then calculated rates of loss for each grid cell between 2000 and 2012.

We merged spatial layers for threatened (Vulnerable, Endangered and Critically Endangered) species distributions that were directly associated with mangroves: *Caretta caretta*, *Chelonia mydas*, *Crocodylus acutus*, *Dugong dugon*, *Eretmochelys imbricate*, *Hemipristis elongata*, *Negaprion brevirostris*, *Osteolaemus tetraspis*, *Platanista gangetica*, *Pristis pectinate*, *Pristis zijsron*, *Sotalia fluviatilis* and *Trichechus manatus*. We clipped the merged species layer using the mangrove loss layer's extent and performed a spatial join. We then used the summary statistics tool to determine the number of species inhabiting each cell. We selected only cells within the top 10th percentile of loss for cells that experienced loss (i.e. cells with no change or increases were excluded prior to percentile calculation).

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Appendix C. Summary information from the literature review highlighting the number and type of associations recorded for each species, and how that association was determined. Also included are species that have seagrass, saltmarsh or mangroves listed as a habitat within their IUCN species assessment, but that were not identified in the literature review (‘IUCN assessment’ under Example reference). Note that studies that found a direct habitat association (e.g. grazing) were not also recorded as finding an indirect association (i.e. occurrence) even though that the species by definition must have occurred in the habitat.

Class	Order	Common name	Species name	IUCN status	Habitat	Method	Association	Example reference
Chondrichthyes								
	Carcharhiniiformes							
		Atlantic sharpnose shark	<i>Rhizoprionodon terraenovae</i>	Least Concern	Seagrass	Isotope	Foraging	Moncreiff and Sullivan 2001
		Australian blacktip shark	<i>Carcharhinus tilstoni</i>	Least Concern	Seagrass	ElectronicTag	Occurrence	Munroe et al 2016
		Australian sharpnose shark	<i>Rhizoprionodon taylori</i>	Least Concern	Seagrass	ElectronicTag	Occurrence	Munroe et al 2014
						Visual	Occurrence	Blaber et al 1992
		Australian weasel shark	<i>Hemigaleus australiensis</i>	Least Concern	Mangroves	Diet	Foraging	Blaber 1986
					Seagrass	Visual	Occurrence	Taylor and Bennett 2008
		Banded houndshark	<i>Triakis scyllium</i>	Least Concern	Seagrass			IUCN assessment
					Saltmarsh			IUCN assessment
		Blackspotted smoothhound	<i>Mustelus punctulatus</i>	Data Deficient	Seagrass			IUCN assessment
		Blacktip reef shark	<i>Carcharhinus melanopterus</i>	Near Threatened	Mangroves	ElectronicTag	Occurrence	Chin et al 2013
					Seagrass	Visual	Occurrence	Blaber et al 1992
		Blacktip shark	<i>Carcharhinus limbatus</i>	Near Threatened	Mangroves	Diet	Foraging	Blaber 1986
						ElectronicTag	Breeding	Heupel and Simpfendorfer 2002
						Visual	Occurrence	White and Potter 2004
					Seagrass	ElectronicTag	Breeding	Legare et al 2015
							Occurrence	DeAngelis et al 2008
						Visual	Occurrence	White and Potter 2004
		Bonnethead shark	<i>Sphyrna tiburo</i>	Least Concern	Mangroves	Visual	Occurrence	Jennings et al 2012
					Seagrass	Diet	Feeding/Foraging	Bethea et al 2007
						Isotope	Foraging	Moncreiff and Sullivan 2001

Brown smoothhound	<i>Mustelus henlei</i>	Least Concern	Seagrass	Visual	Occurrence	Jennings et al 2012
				Visual	Occurrence	Russo et al 2015
				Breeding	Occurrence	Russo et al 2015
Bull shark	<i>Carcharhinus leucas</i>	Near Threatened	Saltmarsh	Visual	Occurrence	Russo et al 2015
				Breeding	Occurrence	Russo et al 2015
			Mangroves	ElectronicTag	Breeding	Matich and Heithaus 2014
				ElectronicTag	Occurrence	Yeiser et al 2008
				Visual	Occurrence	Jennings et al 2012
Caribbean reef shark	<i>Carcharhinus perezii</i>	Near Threatened	Seagrass	Visual	Occurrence	Clark et al 2009
Creek whaler	<i>Carcharhinus fitzroyensis</i>	Least Concern	Seagrass	ElectronicTag	Occurrence	Munroe et al 2015
Daggernose shark	<i>Isogomphodon oxyrinchus</i>	Critically Endangered	Mangroves	Visual	Occurrence	Lessa et al 1999
Graceful shark	<i>Carcharhinus amblyrhynchoides</i>	Near Threatened	Seagrass	Visual	Occurrence	Blaber et al 1992
Gray smooth-hound	<i>Mustelus californicus</i>	Least Concern	Seagrass	ElectronicTag	Occurrence	Espinoza et al 2011
Grey reef shark	<i>Carcharhinus amblyrhynchos</i>	Near Threatened	Seagrass	Visual	Occurrence	Heithaus 2004
Gulf catshark	<i>Asymbolus vincenti</i>	Least Concern	Seagrass			IUCN assessment
Gummy shark	<i>Mustelus antarcticus</i>	Least Concern	Seagrass	ElectronicTag	Occurrence	Barnett et al 2012
Lemon shark	<i>Negaprion brevirostris</i>	Near Threatened	Mangroves	Diet	Foraging	Newman et al 2010
				ElectronicTag	Breeding	Legare et al 2015
					Occurrence	Guttridge et al 2012
			Seagrass	Visual	Breeding	Morgan et al 2015
					Occurrence	Jennings et al 2012
				ElectronicTag	Breeding	Legare et al 2015
					Occurrence	DeAngelis et al 2008
Leopard shark	<i>Triakis semifasciata</i>	Least Concern	Seagrass	Visual	Breeding	DeAngelis et al 2008
					Occurrence	Jennings et al 2012
			Saltmarsh	Visual	Occurrence	Russo et al 2015
				Breeding	Occurrence	Russo et al 2015
Long nosed shark	<i>Carcharhinus hemiodon</i>	Critically Endangered	Seagrass			IUCN assessment

Milk shark	<i>Rhizoprionodon acutus</i>	Least Concern	Seagrass	Diet	Foraging	White et al 2004
				Visual	Occurrence	White and Potter 2004
Nervous shark	<i>Carcharhinus cautus</i>	Data Deficient	Mangroves	Diet	Foraging	Blaber 1986
				ElectronicTag	Occurrence	Escalle et al 2015
				Visual	Occurrence	White and Potter 2004
			Seagrass	Diet	Foraging	White et al 2004
				Isotope	Foraging	Vaudo and Heithaus 2011
				Visual	Occurrence	White and Potter 2004
Northern river shark	<i>Glyphis garricki</i>	Critically Endangered	Mangroves	Visual	Occurrence	Thorburn and Morgan 2004
Pigeye shark	<i>Carcharhinus amboinensis</i>	Data Deficient	Seagrass	ElectronicTag	Occurrence	Knip et al 2011
Sandbar shark	<i>Carcharhinus plumbeus</i>	Vulnerable	Seagrass	Visual	Occurrence	White and Potter 2004
Scalloped hammerhead	<i>Sphyrna lewini</i>	Endangered	Mangroves	Visual	Occurrence	Llerena-Martillo et al 2018
School shark / Tope	<i>Galeorhinus galeus</i>	Vulnerable	Seagrass	ElectronicTag	Occurrence	Barnett et al 2012
Sharptooth lemon shark	<i>Negaprion acutidens</i>	Vulnerable	Mangroves	Visual	Occurrence	White and Potter 2004
				Diet	Foraging	Blaber 1986
			Seagrass	Visual	Occurrence	Blaber et al 1992
Smalltail shark	<i>Carcharhinus porosus</i>	Data Deficient	Seagrass			IUCN assessment
Snaggletooth shark	<i>Hemipristis elongata</i>	Vulnerable	Mangroves	Diet	Foraging	Blaber 1986
			Seagrass			IUCN assessment
Speartooth shark	<i>Glyphis glyphis</i>	Endangered	Mangroves	Visual	Occurrence	Peverell et al 2006
Spinner shark	<i>Carcharhinus brevipinna</i>	Near Threatened	Seagrass	Visual	Occurrence	White and Potter 2004
Spottail shark	<i>Carcharhinus sorrah</i>	Near Threatened	Seagrass	Visual	Occurrence	Knip et al 2012
Tiger shark	<i>Galeocerdo cuvier</i>	Near Threatened	Seagrass	Animal-borne videos	Occurrence	Heithaus et al 2002
				Diet	Foraging	Heithaus et al 2001
				ElectronicTag	Occurrence	Heithaus and Dill 2002
				Isotope	Foraging	Ferreira et al 2017
Whiskery shark	<i>Furgaleus macki</i>	Least Concern	Seagrass	Visual	Occurrence	White and Potter 2004
Whitecheek shark	<i>Carcharhinus dussumieri</i>	Endangered	Seagrass	Visual	Occurrence	Blaber et al 1992
Heterodontiformes						
Crested hornshark	<i>Heterodontus galeatus</i>	Least Concern	Seagrass			IUCN assessment
Japanese bullhead shark	<i>Heterodontus japonicus</i>	Least Concern	Seagrass			IUCN assessment
Port Jackson shark	<i>Heterodontus portusjacksoni</i>	Least Concern	Seagrass	Visual	Occurrence	Powter and Gladstone 2008

				Visual	Breeding	Powter and Gladstone 2008
Hexanchiformes						
Broadnose sevengill shark	<i>Notorynchus cepedianus</i>	Data Deficient	Seagrass	ElectronicTag	Occurrence	Barnett et al 2012
				Visual	Occurrence	Russo et al 2015
			Saltmarsh	Visual	Occurrence	Russo et al 2015
Myliobatiformes						
Atlantic stingray	<i>Hypanus sabinus</i>	Least Concern	Seagrass	Isotope	Foraging	Moncreiff and Sullivan 2001
				Visual	Occurrence	Snelson et al 1988
Bat ray	<i>Myliobatis californicus</i>	Least Concern	Saltmarsh			IUCN assessment
Blackspotted whipray	<i>Maculabatis astra</i>	Least Concern	Seagrass	Isotope	Foraging	Vaudo and Heithaus 2011
Bleeker's variegated whipray	<i>Himantura undulata</i>	Vulnerable	Mangroves			IUCN assessment
Bluntnose stingray	<i>Hypanus say</i>	Least Concern	Seagrass			IUCN assessment
Broad cowtail ray	<i>Pastinachus atrus</i>	Least Concern	Mangroves	ElectronicTag	Occurrence	Cerutti-Pereyra et al 2014
			Seagrass	Isotope	Foraging	Vaudo and Heithaus 2011
Brown whipray	<i>Maculabatis toshi</i>	Least Concern	Mangroves			IUCN assessment
Bullray	<i>Aetomylaeus bovinus</i>	Data Deficient	Seagrass			IUCN assessment
Bullseye round stingray	<i>Urobatis concentricus</i>	Data Deficient	Saltmarsh			IUCN assessment
California butterfly ray	<i>Gymnura marmorata</i>	Least Concern	Seagrass			IUCN assessment
Cortez round stingray	<i>Urobatis maculatus</i>	Data Deficient	Saltmarsh			IUCN assessment
Cownose ray	<i>Rhinoptera bonasus</i>	Near Threatened	Seagrass	Visual	Foraging	Orth 1975
			Saltmarsh	Diet	Foraging	Smith and Merriner 1985
Cowtail ray	<i>Pastinachus sephen</i>	Near Threatened	Mangroves	Visual	Occurrence	White and Potter 2004
Dwarf round stingray	<i>Urotrygon nana</i>	Data Deficient	Mangroves			IUCN assessment
Estuary stingray	<i>Hemitrygon fluviorum</i>	Vulnerable	Seagrass			IUCN assessment
Giant manta ray	<i>Mobula birostris</i>	Vulnerable	Seagrass	Visual	Occurrence	Adams and Amesbury 1998
Golden cownose ray	<i>Rhinoptera steindachneri</i>	Near Threatened	Saltmarsh			IUCN assessment
Hortle's whipray	<i>Pateobatis hortlei</i>	Vulnerable	Mangroves			IUCN assessment
Javanese cownose ray	<i>Rhinoptera javanica</i>	Vulnerable	Seagrass			IUCN assessment
Leopard whipray	<i>Himantura leoparda</i>	Vulnerable	Mangroves			IUCN assessment
Lobed stingaree	<i>Urolophus lobatus</i>	Least Concern	Seagrass			IUCN assessment
Longhead eagle ray	<i>Aetobatus flagellum</i>	Endangered	Seagrass			IUCN assessment
Longnose eagle ray	<i>Myliobatis longirostris</i>	Near Threatened	Saltmarsh			IUCN assessment
Longsnout butterfly ray	<i>Gymnura crebripunctata</i>	Data Deficient	Seagrass			IUCN assessment

Longtail butterfly ray	<i>Gymnura poecilura</i>	Near Threatened	Seagrass			IUCN assessment
			Saltmarsh			IUCN assessment
Mangrove whipray	<i>Urogymnus granulata</i>	Vulnerable	Seagrass	Visual	Occurrence	Blaber et al 1992
			Mangroves	ElectronicTag	Occurrence	Davy et al 2015
Manta raya	<i>Hypanus dipterurus</i>	Data Deficient	Saltmarsh			IUCN assessment
Masked stingaree	<i>Trygonoptera personata</i>	Least Concern	Seagrass			IUCN assessment
Maskray	<i>Neotrygon</i> sp.		Seagrass	Isotope	Foraging	Vaudo and Heithaus 2011
Mottled eagle ray	<i>Aetomylaeus maculatus</i>	Endangered	Seagrass			IUCN assessment
Ornate eagle ray	<i>Aetomylaeus vespertilio</i>	Endangered	Mangroves	Visual	Occurrence	White and Potter 2004
			Seagrass			IUCN assessment
Pink whipray	<i>Pateobatis fai</i>	Vulnerable	Seagrass	Diet	Foraging	Vaudo and Heithaus 2011
				Isotope	Foraging	Vaudo and Heithaus 2011
				Visual	Occurrence	Vaudo et al 2013
Plain maskray	<i>Neotrygon annotata</i>	Near Threatened	Seagrass			IUCN assessment
Porcupine ray	<i>Urogymnus asperrimus</i>	Vulnerable	Mangroves	ElectronicTag	Occurrence	Cerutti-Pereyra et al 2014
Reef manta ray	<i>Mobula alfredi</i>	Vulnerable	Seagrass			IUCN assessment
Reticulate whipray	<i>Himantura uarnak</i>	Vulnerable	Mangroves	ElectronicTag	Occurrence	Cerutti-Pereyra et al 2014
				Visual	Occurrence	White and Potter 2004
			Seagrass	Diet	Foraging	Vaudo and Heithaus 2011
				Isotope	Foraging	Vaudo and Heithaus 2011
				Visual	Occurrence	Vaudo et al 2013
Roughnose stingray	<i>Pastinachus solocirostris</i>	Endangered	Mangroves			IUCN assessment
Round stingray	<i>Urolophus halleri</i>	Least Concern	Seagrass	Visual	Occurrence	Reed and Hovel 2006
Round whipray	<i>Maculabatis pastinacoides</i>	Vulnerable	Mangroves			IUCN assessment
Scaly whipray	<i>Brevitrygon imbricata</i>	Data Deficient	Mangroves			IUCN assessment
Sharpnose stingray	<i>Telatrygon zugei</i>	Near Threatened	Seagrass			IUCN assessment
Sinclair's/Spotted stingaree	<i>Urolophus gigas</i>	Least Concern	Seagrass			IUCN assessment
Smooth butterfly ray	<i>Gymnura micrura</i>	Data Deficient	Seagrass			IUCN assessment
Southern eagle ray	<i>Myliobatis tenuicaudatus</i>	Least Concern	Seagrass	Visual	Occurrence	Harvey et al 2012
Southern stingray	<i>Hypanus americanus</i>	Data Deficient	Mangroves	Visual	Occurrence	Jennings et al 2012
			Saltmarsh			IUCN assessment
			Seagrass	Visual	Occurrence	Jennings et al 2012
				Visual	Foraging	Williams 1988

	Sparsely-spotted stingaree	<i>Urolophus paucimaculatus</i>	Least Concern	Seagrass			IUCN assessment
	Striped stingaree	<i>Trygonoptera ovalis</i>	Least Concern	Seagrass			IUCN assessment
	Spotted eagle ray B	<i>Aetobatus ocellatus</i>	Vulnerable	Seagrass	Isotope	Foraging	Vaudo and Heithaus 2011
	Tubemouth whipray	<i>Urogymnus lobistoma</i>	Vulnerable	Mangroves			IUCN assessment
	Tumbes round stingray	<i>Urobatis tumbesensis</i>	Data Deficient	Mangroves			IUCN assessment
	Western shovelnose stingaree	<i>Trygonoptera mucosa</i>	Least Concern	Seagrass			IUCN assessment
	Whitespotted eagle rays	<i>Aetobatus narinari</i>	Near Threatened	Mangroves	Visual	Occurrence	Jennings et al 2012
				Seagrass	Visual	Occurrence	Jennings et al 2012
	Yellow stingray	<i>Urobatis jamaicensis</i>	Least Concern	Mangroves	Visual	Occurrence	Jennings et al 2012
				Seagrass	Visual	Occurrence	Jennings et al 2012
	Zonetail butterfly ray	<i>Gymnura zonura</i>	Vulnerable	Seagrass			IUCN assessment
Orectolobiformes							
	Arabian carpetshark	<i>Chiloscyllium arabicum</i>	Near Threatened	Mangroves			IUCN assessment
	Blind shark	<i>Brachaelurus waddi</i>	Least Concern	Seagrass			IUCN assessment
	Cenderwasih epaulette shark	<i>Hemiscyllium galei</i>	Data Deficient	Seagrass			IUCN assessment
	Colclough's carpetshark	<i>Brachaelurus colcloughi</i>	Vulnerable	Seagrass	Visual	Occurrence	Kyne et al 2011
	Grey carpetshark	<i>Chiloscyllium punctatum</i>	Near Threatened	Seagrass	Isotope	Foraging	Vaudo and Heithaus 2011
					Visual	Occurrence	White and Potter 2004
	Henry's epaulette shark	<i>Hemiscyllium henryi</i>	Data Deficient	Seagrass			IUCN assessment
	Michael's epaulette shark	<i>Hemiscyllium michaeli</i>	Near Threatened	Seagrass			IUCN assessment
	Nurse shark	<i>Ginglymostoma cirratum</i>	Data Deficient	Mangroves	Visual	Occurrence	Jennings et al 2012
				Seagrass	Visual	Occurrence	Jennings et al 2012
	Ornate wobbegong	<i>Orectolobus ornatus</i>	Least Concern	Seagrass	Visual	Occurrence	Heithaus 2004
	Papuan epaulette shark	<i>Hemiscyllium hallstromi</i>	Vulnerable	Seagrass			IUCN assessment
	Rusty carpetshark	<i>Parascyllium ferrugineum</i>	Least Concern	Seagrass			IUCN assessment
	Spotted wobbegong	<i>Orectolobus maculatus</i>	Least Concern	Seagrass			IUCN assessment
	Tawny nurse shark	<i>Nebrius ferrugineus</i>	Vulnerable	Seagrass			IUCN assessment
	Varied carpetshark	<i>Parascyllium variolatum</i>	Least Concern	Seagrass			IUCN assessment
	Zebra shark	<i>Stegostoma fasciatum</i>	Endangered	Seagrass			IUCN assessment
Rajiformes							
	Brown skate	<i>Raja miraletus</i>	Least Concern	Seagrass			IUCN assessment
Rhinopristiformes							
	Dwarf sawfish	<i>Pristis clavata</i>	Endangered	Mangroves	Visual	Occurrence	Peverell 2005

			Seagrass			IUCN assessment
Eastern fiddler ray	<i>Trygonorrhina fasciata</i>	Least Concern	Seagrass			IUCN assessment
Eastern shovelnose ray	<i>Aptychotrema rostrata</i>	Least Concern	Seagrass			IUCN assessment
Freckled guitarfish	<i>Pseudobatos lentiginosus</i>	Near Threatened	Seagrass	Visual	Occurrence	Sogard et al 1989
Giant shovelnose ray	<i>Glaucostegus typus</i>	Vulnerable	Mangroves	ElectronicTag	Occurrence	Cerutti-Pereyra et al 2014
				Visual	Occurrence	White and Potter 2004
			Seagrass	Diet	Foraging	Vaudo and Heithaus 2011
				Isotope	Foraging	Vaudo and Heithaus 2011
				Visual	Occurrence	Vaudo et al 2013
Indonesian guitarfish	<i>Rhinobatos penggali</i>	Vulnerable	Seagrass			IUCN assessment
			Mangroves			IUCN assessment
Jimbaran guitarfish	<i>Rhinobatos jimbaranensis</i>	Vulnerable	Seagrass			IUCN assessment
Green sawfish	<i>Pristis zijsron</i>	Critically Endangered	Mangroves	Visual	Breeding	Morgan et al 2015
				Visual	Occurrence	White and Potter 2004
			Seagrass			IUCN assessment
Largeetooth sawfish	<i>Pristis pristis</i>	Critically Endangered	Mangroves	Visual	Occurrence	Peverell 2005
			Seagrass			IUCN assessment
Narrow sawfish	<i>Anoxypristis cuspidata</i>	Endangered	Mangroves	Visual	Occurrence	Peverell 2005
			Seagrass			IUCN assessment
Smalltooth sawfish	<i>Pristis pectinata</i>	Critically Endangered	Mangroves	ElectronicTag	Occurrence	Papastamatiou et al 2015
					Breeding	Guttridge et al 2015
				Visual	Occurrence	Jennings et al 2012
					Breeding	Simpfendorfer et al 2010
			Seagrass	ElectronicTag	Occurrence	Papastamatiou et al 2015
				Visual	Occurrence	Jennings et al 2012
Smoothnose wedgefish	<i>Rhynchobatus laevis</i>	Vulnerable	Seagrass	Isotope	Foraging	Vaudo and Heithaus 2011
Thornback fanray	<i>Platyrrhinoidis triseriata</i>	Least Concern	Saltmarsh			IUCN assessment
Whitenose guitarfish	<i>Pseudobatos leucorhynchus</i>	Near Threatened	Saltmarsh			IUCN assessment
Squatiniformes						
Australian angel shark	<i>Squatina australis</i>	Least Concern	Seagrass			IUCN assessment
North Pacific spiny dogfish	<i>Squalus suckleyi</i>	Least Concern	Seagrass	Visual	Occurrence	Penaluna and Bodenteiner 2015

Mammalia	Torpediniformes						
	Caribbean electric ray	<i>Narcine bancroftii</i>	Critically Endangered	Seagrass			IUCN assessment
	Leopard numbfish	<i>Narcine leoparda</i>	Near Threatened	Mangroves			IUCN assessment
	Spotted torpedo	<i>Torpedo marmorata</i>	Data Deficient	Seagrass			IUCN assessment
	Variegated electric ray	<i>Diplobatis pictus</i>	Vulnerable	Seagrass			IUCN assessment
	Carnivora						
	American mink	<i>Neovison vison</i>	Least Concern	Mangroves	Visual	Occurrence	Humphrey and Zinn 1982
				Saltmarsh	Visual	Occurrence	Humphrey and Zinn 1982
	Asian small-clawed otter	<i>Aonyx cinereus</i>	Vulnerable	Mangroves	Visual	Occurrence	Aziz 2018
				Saltmarsh			IUCN assessment
	Australian sea lion	<i>Neophoca cinerea</i>	Endangered	Seagrass	ElectronicTag	Occurrence	Lowther et al 2011
					Isotope	Foraging	Lowther et al 2011
	Cape clawless otter	<i>Aonyx capensis</i>	Near Threatened	Mangroves	Visual	Occurrence	Angelici et al 2005
				Saltmarsh			IUCN assessment
	Eurasian otter	<i>Lutra lutra</i>	Near Threatened	Saltmarsh			IUCN assessment
	Hair-nosed otter	<i>Lutra sumatrana</i>	Endangered	Mangroves	Visual	Occurrence	Heng et al 2016
				Saltmarsh			IUCN assessment
	Harbour seal	<i>Phoca vitulina</i>	Least Concern	Saltmarsh			IUCN assessment
	Neotropical otter	<i>Lontra longicaudis</i>	Near Threatened	Mangroves	Feecal	Foraging	Rheingantz et al 2012
				Saltmarsh			IUCN assessment
	North American river otter	<i>Lutra canadensis</i>	Least Concern	Mangroves	Visual	Occurrence	Humphrey and Zinn 1982
				Saltmarsh	Visual	Occurrence	Humphrey and Zinn 1982
	Sea otter	<i>Enhydra lutris</i>	Endangered	Seagrass	Visual	Foraging	Hessing-Lewis et al 2018
				Saltmarsh	Visual	Foraging	Eby et al 2017
	Smooth-coated otter	<i>Lutrogale perspicillata</i>	Vulnerable	Mangroves	Visual	Occurrence	Kamjing et al 2017
				Saltmarsh			IUCN assessment
	Southern river otter	<i>Lontra provocax</i>	Endangered	Saltmarsh			IUCN assessment
	Spotted-necked otter	<i>Hydricitis maculicollis</i>	Near Threatened	Mangroves			IUCN assessment
	Cetacea						
	Amazon River dolphin	<i>Inia geoffrensis</i>	Endangered	Mangrove	Visual	Occurrence	Costa et al 2013
	Bottlenose dolphin	<i>Tursiops sp.</i>	Least Concern	Mangroves	Contaminant levels	Occurrence	Damseaux et al 2017

Sirenia	Ganges river dolphin	<i>Platanista gangetica gangetica</i>	Endangered	Mangroves	Visual	Foraging	Sarabia et al 2017
						Occurrence	Grigg and Markowitz 1997
					Saltmarsh	Visual	Foraging
					Seagrass	Acoustics	Occurrence
						Diet	Foraging
						Isotope	Foraging
						Visual	Foraging
							Occurrence
					Acoustics	Occurrence	Jensen et al 2013
					Visual	Occurrence	Smith et al 2010
	Guiana dolphin	<i>Sotalia guianensis</i>	Near Threatened	Mangroves	Visual	Occurrence	Monteiro-Filho and Monteiro 2001
	Indian Ocean humpback dolphin	<i>Sousa plumbea</i>	Endangered	Mangroves			IUCN assessment
	Indo-Pacific finless porpoise	<i>Neophocaena phocaenoides</i>	Vulnerable	Seagrass			IUCN assessment
	Indo-Pacific humpback dolphin	<i>Sousa chinensis</i>	Vulnerable	Mangroves	Visual	Occurrence	Collins et al 2005
				Saltmarsh			IUCN assessment
					Acoustics	Occurrence	Hoffman et al 2015
					Visual	Occurrence	Smith et al 2006
	Irrawaddy dolphin	<i>Orcaella brevirostris</i>	Endangered	Seagrass	Visual	Occurrence	Parra 2006
				Mangroves	Acoustics	Occurrence	Hoffman et al 2017
					Visual	Occurrence	Smith et al 2010
	La Plata dolphin	<i>Pontoporia blainvillei</i>	Vulnerable	Mangrove	Visual	Occurrence	Cremer and Simoes-Lopes 20005
	Narrow-ridged finless porpoise	<i>Neophocaena asiaeorientalis</i>	Endangered	Seagrass			IUCN assessment
	Snubfin dolphin	<i>Orcaella heinsohni</i>	Vulnerable	Mangroves			IUCN assessment
				Saltmarsh			IUCN assessment
				Seagrass	Visual	Occurrence	Parra 2006
	Spinner dolphin	<i>Stenella longirostris</i>	Least Concern	Seagrass	Visual	Foraging	Trianni and Kessler 2002
	Tucuxi dolphin	<i>Sotalia fluviatilis</i>	Data Deficient	Mangrove	Visual	Occurrence	de Oliverira Santos 2001
	African manatee	<i>Trichechus senegalensis</i>	Vulnerable	Mangroves	Visual	Occurrence	Luiselli et al 2012
				Seagrass			IUCN assessment
				Saltmarsh			IUCN assessment

Reptilia	Crocodylia	Dugong	<i>Dugong dugon</i>	Vulnerable	Mangroves	Diet	Feeding	Johnstone and Hudson 1981
						Visual	Occurrence	Anderson and Birtles 1978
					Seagrass	Acoustics	Feeding	Tsutsumi et al 2006
							Occurrence	Tanaka et al 2017
						Contaminant levels	Feeding	McLachlan et al 2001
						Diet	Feeding	Tol et al 2017
						ElectronicTag	Occurrence	Hagihara et al 2018
						Isotope	Feeding	Clementz et al 2007
						Visual	Breeding	Adulyanukosol and Poovachiranon 2006
							Feeding	D'Souza et al 2015
							Occurrence	D'Souza et al 2015
						Visual - feeding evidence	Feeding	Mizuno et al 2017
		Florida manatee	<i>Trichechus manatus latirostris</i>	Endangered	Mangroves	Visual	Feeding	Fertl et al 2005
					Saltmarsh	Visual	Feeding	Baugh et al 1989
					Seagrass	Diet	Feeding	Worthy and Worthy 2013
						ElectronicTag	Occurrence	Rycyk et al 2018
						Isotope	Feeding	Alves-Stanley et al 2010
						Visual	Feeding	Lefebvre et al 2017
							Occurrence	Semeyn et al 2011
		West Indian manatee	<i>Trichechus manatus manatus</i>	Endangered	Mangroves	Visual	Feeding	Spiegelberger and Ganslosser 2005
							Occurrence	de Oliverira 2013
					Seagrass	Diet	Feeding	Allen et al 2017
						Isotope	Feeding	Alves-Stanley et al 2010
						Visual	Feeding	LaCommare et al 2008
						Visual - feeding evidence	Feeding	Bacchus et al 2009
		American alligator	<i>Alligator mississippiensis</i>	Least Concern	Mangroves	ElectronicTag	Occurrence	Rosenblatt et al 2013

Testudines	American crocodile	<i>Crocodylus acutus</i>	Vulnerable	Saltmarsh	Diet	Foraging	Nifong et al 2015
					Isotope	Foraging	Nifong et al 2015
					Visual	Nesting	Platt et al 1995
						Occurrence	Nifong et al 2015
	Dwarf crocodile	<i>Osteolaemus tetraspis</i>	Vulnerable	Mangroves	Visual	Breeding	Ogden 1978
					Visual	Occurrence	Vanagas-Anaya et al 2014
	Morelet's crocodile	<i>Crocodylus moreletii</i>	Least Concern	Mangroves	Diet	Foraging	Pauwels et al 2007
					Visual	Occurrence	Pauwels et al 2007
	Nile crocodile	<i>Crocodylus moreletii</i>	Least Concern	Mangroves	Visual	Breeding	Platt et al 2008
					Visual	Occurrence	Platt and Thorbjarnarson 2000
	Saltwater crocodile	<i>Crocodylus niloticus</i>	Least Concern	Mangroves	Visual	Occurrence	Kofron 1992
					Visual	Occurrence	Kofron 1992
	West African crocodiles	<i>Crocodylus porosus</i>	Least Concern	Mangroves	Visual	Breeding	Gopi et al 2007
						Occurrence	Hassan et al 2018
	West African crocodiles	<i>Crocodylus suchus</i>	Data Deficient	Mangroves	Visual	Occurrence	Luiselli et al 2012
		<i>Caiman crocodilus fuscus</i>	Data Deficient	Mangroves	Visual	Occurrence	Bolanos et al 1997
Testudines	Green turtle	<i>Chelonia mydas</i>	Endangered	Mangroves	Diet	Feeding	Gama et al 2016
					Isotope	Feeding	Prior et al 2015
					Visual	Feeding	Limpus and Limpus 2000
						Occurrence	Jennings et al 2012
				Saltmarsh	Diet	Feeding	Nagaoka et al 2012
				Seagrass	Animal-borne videos	Feeding	Thomson et al 2015
					Diet	Feeding	Christianen et al 2018
					ElectronicTag	Feeding	Whiting and Miller 1998
						Occurrence	Thomson et al 2018
					Fatty Acid	Feeding	Seaborn 2005
					Isotope	Feeding	Gillis et al 2018
							van Tussenbroek and Morales 2017
					Visual	Feeding	2017
						Occurrence	Al-Mansi 2016
					Visual - feeding evidence	Feeding	Molina and Tussenbroek 2014

Hawksbill turtle	<i>Eretmochelys imbricata</i>	Critically Endangered	Mangroves	ElectronicTag	Occurrence	Gaos et al 2012
				Visual	Breeding	Gaos et al 2017
					Occurrence	Gaos et al 2018
			Seagrass	Diet	Feeding/Foraging	Stringell et al 2016
				ElectronicTag	Occurrence	Hoenner et al 2016
				Isotope	Feeding	Bjorndal 2010
				Visual	Occurrence	Gorham et al 2014
Kemp's Ridley turtle	<i>Lepidochelys kempii</i>	Critically Endangered	Mangroves	Visual	Occurrence	Schmid and Tucker 2018
			Seagrass	Diet	Foraging	Schmid and Tucker 2018
				ElectronicTag	Occurrence	Schmid et al 2003
Loggerhead turtle	<i>Caretta caretta</i>	Vulnerable	Mangroves	Visual	Breeding	Foley et al 2000
					Occurrence	Jennings et al 2012
			Saltmarsh	ElectronicTag	Occurrence	Stoneburner et al 1982
			Seagrass	Diet	Foraging	Witherington 2002
				Isotope	Foraging	Belicka et al 2012
				Visual	Foraging	Preen 1996
					Occurrence	Jennings et al 2012

Appendix D. Number of species from each taxonomic group with habitat association with vegetated coastal wetlands.

Figure 1. The number of species for each of the key taxonomic groups that occur, graze, forage and breed in vegetated coastal wetlands – mangroves, saltmarshes and seagrasses.

Appendix E. Vegetated coastal wetland-associated marine megafauna distributions (full size maps from Box 2).

Figure 1. Heatmaps of biodiversity for 172 of the 173 marine megafauna identified as having an association with vegetated coastal wetlands. The blue dots represent locations of field studies from the literature review, and the graded colours represent species richness (see Key).

Figure 2. The number of species (only for species that are listed as threatened under IUCN and associated with mangroves from our literature search; $n = 13$) with distributions that intersect with high rates of mangrove loss (D – F). Mangrove loss (2000-2012) was calculated for all $0.2^\circ \times 0.2^\circ$ cells using

data from Hamilton and Casey [1], and we show only cells within the top 10th percentile for cells that experienced some loss over this time (i.e. cells with no change or increases were excluded prior to percentile calculation). See Appendix A for mapping methodology.

References

1. Hamilton, S.E. and Casey, D. (2016) Creation of a high spatio- temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC- 21). *Global Ecology and Biogeography* 25 (6), 729-738.