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MEMORANDUM OF UNDERSTANDING ON THE CONSERVATION AND MANAGEMENT OF MARINE TURTLES AND THEIR HABITATS OF THE INDIAN OCEAN AND SOUTH-EAST ASIA

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THE VULNERABILITY OF *CASUARINA*-BACKED SEA TURTLE NESTING BEACHES TO EROSION

(Prepared by the Advisory Committee)

Action requested:

- Take note of the report
- Consider implications for marine turtle conservation

The vulnerability of *Casuarina*-backed sea turtle nesting beaches to erosion

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The 7th convention of Signatory States of the IOSEA MoU called for an investigation into the general practice of using *Casuarina* trees as a means of stabilizing coastlines. *Casuarina* trees are planted to enhance coastal protection, but it was noted with concern that *Casuarina* trees are used in non-native range. Further, there are doubts about the efficacy in facilitating coastal dune stabilization and protection or the value of enhancing turtle nesting areas where this may result in modification of natural coastal habitat.

Casuarina trees are planted to form green shelter belts and are seen as ecologically preferable to hard armouring; bio-shield proponents argue that shelter belts have the potential to reduce wave impact force, flow depth and velocity (Forbes & Broadhead 2008), and so vegetation absorbs/breaks wave energy as it passes through plantations (Forbes & Broadhead 2008), whereas solid structures such as sea walls, may be overtopped, smashed or eroded. *Casuarina* trees are fast-growing, hardy, withstand salt spray and are an economically feasible option; tree saplings can be planted by inexpensive, low-skilled labourers without requirement for sophisticated engineering skills costly equipment or machinery (Tanaka & Thuy 2010). Trees can be rotationally harvested for timber.

Even though green shelter belts with exotic plants (e.g. forestry in South Africa) have been used extensively, the development of *Casuarina* spp.as green shelter belts became especially popular in the IOSEA region after the December 2004 tsunami event that devastated beaches in the IOSEA region. Some projects considered using this vegetation as a key coastal protection strategy. In the Kanchipuram district of Tamil Nadu in India, for example, an estimated 180 000 *Casuarina* saplings have been planted on 450 ha of coastal habitat (Chaudari et al. 2009). These plantations back olive ridley (*Lepidochelys olivacea*) sea turtles nesting habitat (Chaudari et al. 2009). In fact, almost a third of India's coastline has been covered with plantations, initiated as a response to the December 2004 tsunami event (Chaudari et al. 2009, Mukherjee et al. 2009). In the Batticaloa district of Sri Lanka, *Casuarina* trees were artificially established on approximately 400 ha of the coastline, 50 m inland from the mean high tide line (Mathiventhan & Jayasingum 2014). As a consequence the number of studies evaluating the role of vegetation in attenuating extreme storm and other episodic events also grew rapidly (e.g. Danielsen et al. 2005, Tanaka & Thuy 2010, Samarakoon et al. 2013, Mathiventhan & Jayasingum 2014).

The purpose of this study is to determine whether *Casuarina* trees affect erosion vulnerability of sea turtle nesting beaches throughout the Indian Ocean and South East Asia (IOSEA) region over and above other factors, such as urban development. The specific objectives were 1) to quantify the distribution of non-native *Casuarina* trees on sea turtle nesting beaches of the IOSEA region and 2) to create an erosion vulnerability score (based on risk and threat) for the nesting sites based on global datasets of erosion indicators. Then, 3) to apply the vulnerability index to 50 sea turtle nesting beaches, and 4) to assess whether shores with *Casuarina* trees are more vulnerable to beach erosion than *Casuarina*-free beaches. We hypothesised that the characteristics of *Casuarina* trees are not an effective coastal protection tool and predict that beaches backed by these trees will have higher erosion vulnerability scores than those beaches without these trees.

To establish the occurrence of casuarinas on turtle rookeries across the IOSEA region, several approaches on different scales were considered. First, the global distribution and native ranges were established using three global data sets: The Invasive Species Compendium (CAB International, 2000; http://www.cabi.org/ISC/), Global Biodiversity Information Facility (GBIF 2008; http://www.gbif.org) and Atlas of Living Australia (http://www.ala.org.au/). These datasets, however, do not allow for identification at a local scale (i.e. beach level). To establish *Casuarina* tree occurrence per beach, user-posted images on Google Earth (Pro 7.3.0.3832) Panoromio were used. Geotagged images uploaded by users allowed us to identify *Casuarina* presence and extent along the backshore, but not the species. Only native vs non-native *Casuarina* presence and absence information was indicated with no assumptions about the species or impact.

The vulnerability of turtle nesting beaches to erosion were generated using a PVA styled assessment. We selected 50 important sea turtle nesting beaches (Fig. 1) of the Indian Ocean and South-East Asia (IOSEA) region (details in APPENDIX 1) and used an adapted Coastal Vulnerability Index (CVI) to determine vulnerability of these beaches to erosion. However, to calculate *risk* and *threat* indices, CVI variables were adapted from those presented in the literature (e.g. Benassai et al., 2015). New score variables to interpret these metrics (for risk and threat) needed to be developed. This was developed from a representative global set of beaches (n= > 200) as a comprehensive beach 'training data' set published by Defeo and McLachlan (2013). This training data set was used to select variables and develop categories (**Table 1**). The turtle nesting sites were then assessed using long-term global data sets under four *risk* indicators (backshore width, beach exposure, modal beach energy, dune state) and three *threat* indicators (coastal development, sea-level rise and storminess). If data were unavailable for a specific indicator at a particular site, that datum was indicated as 'data deficient' and, following Wallace et al. (2011), received the highest risk/threat score of that category.

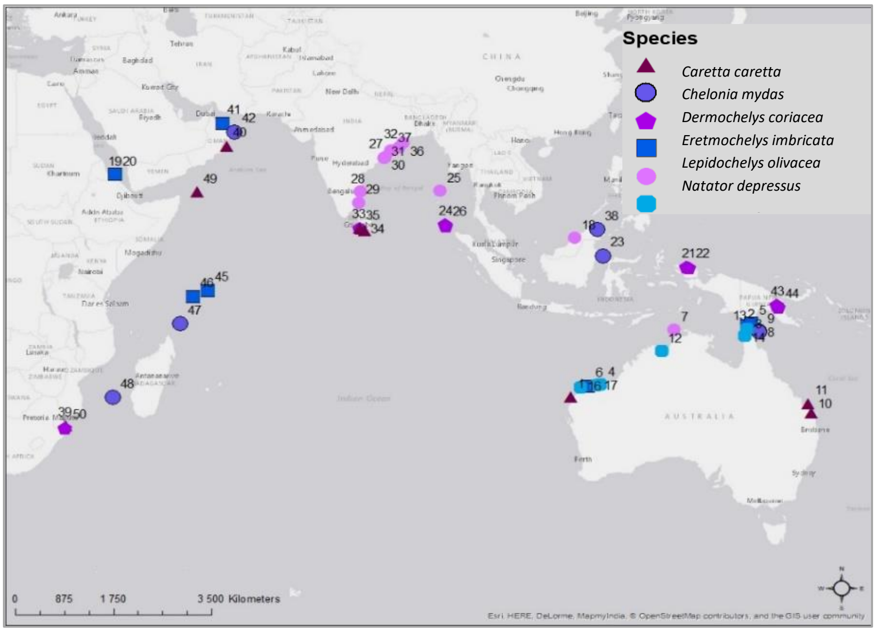

Figure 1. Spatial distribution of 50 sea turtle rookeries representing all six species of sea turtles in the IOSEA region that were used to assess vulnerability to coastal erosion. (Details of each site presented in APPENDIX 1).

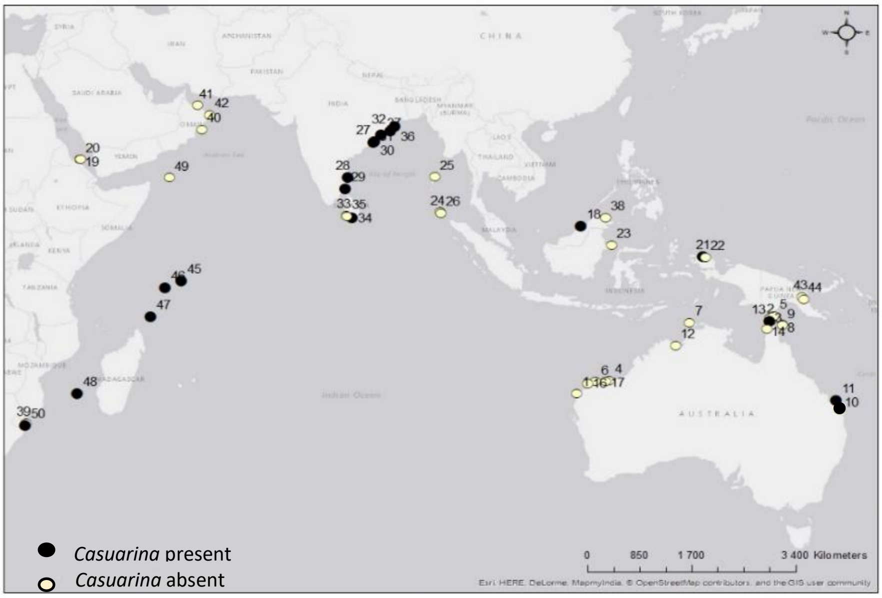

Figure 2. Spatial distribution of 50 sea turtle rookeries with/without *Casuarina* trees. A total of 19 out of 50 turtle nesting beaches are backed by *Casuarina* trees, of which 5 of those had native trees and 14 non-native trees.

Table 1: Coastal Vulnerability Index calculated from different risk and threat categories for various indicators

<table>
<tr><th colspan="4">Beach vulnerability</th></tr>
<tr><th>Risk Indictors</th><th>Score</th><th>Threat Indicators</th><th>Score</th></tr>
<tr><td>1) Back beach width
Based on the width from the high tide line to the foot of the primary dune or the first line of coastal development</td><td>1 = > 26 m
2 = 18 - 26 m
3 = 12 - 18 m
4 = 9 - 12 m
5 = 0 -9 m</td><td>1) Projected sea level rise
Average increase from the 2020's to the 2090's for both the 4.5 and 8.5 RCP scenarios</td><td>1 = 0.33 - 0.36 m
2 = 0.36 - 0.38 m
3 = 0.38 - 0.40 m
4 = 0.40 - 0.48 m
5 = > 0.48 m</td></tr>
<tr><td>2) Beach exposure
Based on surfzone entropy, geomorphological or other structures that may offer shelter and wave direction</td><td>0 = completely sheltered (blocked by a rocky reef or breakwater)
1 = sheltered
2 = semi-exposed, more sheltered than exposed
3 = semi-exposed, more exposed than sheltered
4 = fully exposed</td><td>2) Storm frequency

Storm frequency refers to line density of the NOAA archived storm track data (1848 to 2018) per km^2 (line density tool ArcMap 10.5.1)</td><td>0 = 0
1 = < 0.69
2 = 0.069 - 0.139
3 = 0.139 - 0.208
4 = 0.208 - 0.277
5 = 0.277 - 0.347
6 = 0.347 - 0.416
7 = 0.416 - 0.486
8 = 0.486 - 0.554
9 = 0.554 - 0.624</td></tr>
<tr><td rowspan="3">3) Modal Beach energy
Based on the sum of the modal wave height, wind speed and tidal range</td><td>Waves
0 = Calm (No waves)
1 = Calm (Ripples, 0 – 0.1 m)
2 = Smooth (0.1 – 0.5 m)
3 = Slight (0.5 – 1.25 m)
4 = Moderate (1.25 – 2.5 m)
5 = Rough (2.5 – 4 m)
6 = Very rough (4 – 6 m)
7 = High (6 – 9 m)
8 = Very High (9 – 14 m)
9 = Phenomenal (>14 m)</td><td>3) Storm intensity

Storm intensity refers to the maximum sustained winds (knots) extracted per km^2 from the NOAA archived strom track data (1848 to 2018)</td><td>0 = 0
1 = 10 - 26 knots
2 = 26 - 42 knots
3 = 42 - 58 knots
4 = 58 - 74 knots
5 = 74 - 91 knots
6 = 91 - 107 knots
7 = 107 - 123 knots
8 = 123 - 139 knots
9 = 139 - 155 knots</td></tr>
<tr><td>Wind
0 = Calm (< 1 knots)
1 = Light air (1 – 3 knots)
2 = Light breeze (4 – 6 knots)
3 = Gentle breeze (7 – 10 knots)
4 = Moderate (11 – 16 knots)
5 = Fresh breeze (17 – 21 knots)
6 = Strong breeze (22 – 27)
7 = Moderate gale (28 – 33 knots)
8 = Fresh gale (34 – 40 knots)
9 = Strong gale (41 – 47 knots)
10 = Whole gale (48 – 55 knots)
11 = Storm (56 – 65 knots)
12 = Hurricane (>65 knots)</td><td rowspan="3">4) Coastal development
Based on location, intensity and extent.</td><td rowspan="3">Location of development
0 = None
1 = Secondary dune
2 = Foredune
3 = Back beach

Intensity of development
0 = None
1 = Low
2 = Moderate
3 = High

Extent of development
0 = None
1 = 1/3
2 = 2/3
3 = 3/3</td></tr>
<tr><td>Tide
1 = micro-tidal (<2 m)
2 = meso-tidal (2-4 m)
3 = macro-tidal (>4 m)</td></tr>
<tr><td>4) State of the dunes system
Based on the condition of the dune system</td><td>1= multiple sand dune ridges
2= single sand dune ridge
3= developed or no dunes</td></tr>
</table>

Casuarinas were present on 19 of the 50 turtle sites (Fig. 2); five of these beaches had native *Casuarina* species including a site in Brunei (#18), one in Indonesia (#21) and three Australian sites (#10, #11, #13). The 14 beaches with non-native/introduced *Casuarina* species occurred along the east coast of India and the (French) Scattered Islands north and west of Madagascar, as well as several islands in the Seychelles, and the South African rookery. One site in Sri Lanka, i.e., Rekawa (#34), had a few introduced *Casuarina* covering less than 25% of the back-beach. The seven sites in India, namely Devi river mouth (#32), Gahirmatha (#36), Kalingapatnam (#27), Mamallapuram (#28), Nagapattinam (#29), Rushikulya (#37), Srikakulam (#31) and Srikurmam (#30), had extensive *Casuarina* strips covering more than 25% of the back-beach, very close to the high tide line. Non-native *Casuarina* occurrence was extensive on two of the Seychelles study sites: Cousin Island Special Reserve (#45) and Farquhar Island (#47). Photos and google earth imagery show *Casuarina* were present directly on the back-beach for substantial portions of these two islands.

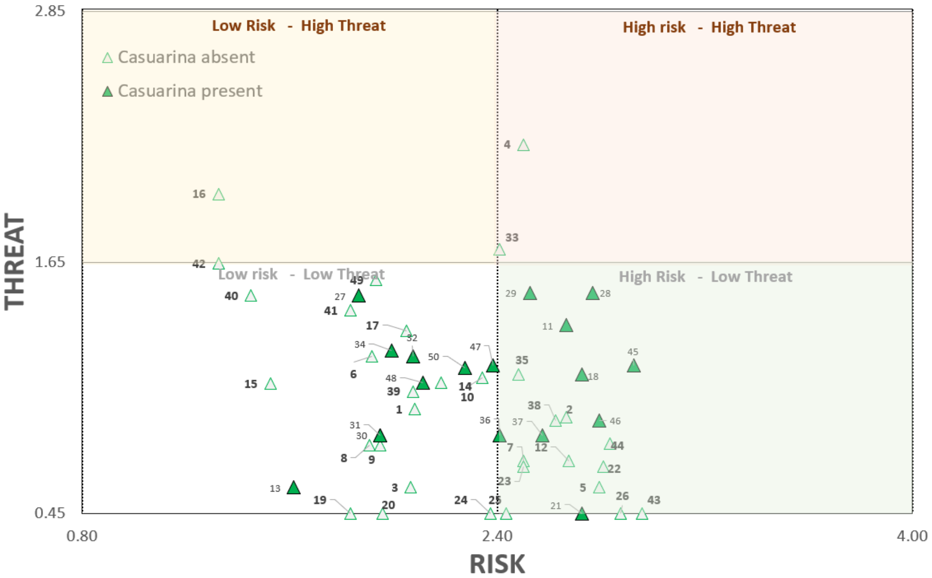

Figure 3. Vulnerability scores for 50 turtle rookeries across the IOSEA region. The risk is rated against backshore width, beach exposure, modal beach energy, and dune state, whereas threat is rated against coastal development, storm frequency and intensity, and sea level rise. Kruskal-Wallis of CVI scores ($\chi^2_{2,44}$ = 42.62, p = 0.5308) indicate no difference in the vulnerability between beaches with/ without casuarinas. Score details summarised in APPENDIX 2.

(Fig. 3): Cemetery beach (#4) and Bentota beach (#33). Both these beaches were distributed within the High Risk-High Threat category. However, since the nests at Bentota beach are relocated to minimise threat of poaching/predation and also for purposes for ecotourism, the eggs are protected (Ekanayake et al., 2010). One beach, Barrow Island (#16) was categorised as Low Risk-High Threat, with 22 beaches categorised as High Risk-Low Threat and 25 beaches within the Low Risk-Low Threat category. Because the sea turtle nesting beaches showed low to moderate modal beach energy, sea-level rise, and storm frequency and intensity, the High Risk-High Threat beaches generally had the following characteristics: narrow backshore width (< 10 m), high beach exposure, no dune system and/or high(er) levels of coastal development. These characteristics increase the erosion potential of beaches. Backshore or dry beach width acts a buffer zone against wave action, therefore wider backshore sections will offer more protection (Anfuso and Martínez Del Pozo, 2009, Rangel-Buitrago and Anfuso, 2015), indicating the narrow backshore sections would make the majority of the sea turtle nesting beaches more vulnerable to oncoming waves (Rizzo et al., 2017). High beach exposure means beach orientation and low/no physical protection allows for direct wave action making beaches more susceptible to sand loss (Bryan et al., 2001; Mclaughlin and Cooper, 2010; Goodhue et al., 2012). If the dune system is compromised through development or if no dunes occur, sand loss might be permanent as dunes act as sand reserves that replenish the beach's sand budget (Tinley, 1985; Tsoar, 2001, Abuodha and Woodroffe, 2006) in addition to continuous replenishment through longshore drift and aeolian transport.

Although *Casuarina* presence may contribute to erosion vulnerability in some cases, the beaches in this study seem to be more vulnerable to erosion as a result of physical characteristics that increase the risk of beach inundation/flooding processes (Gornitz et al., 1994). Certainly, there is a broader distribution of scores along the *risk* axis than *threat* axis, suggesting that if the threat regime had to increase, many beaches would become substantially more vulnerable to erosion. Of the threat factors, coastal development is the only one that can be controlled by beach managers. Management strategies should therefore consider options that reduces the risk of erosion and episodic inundation, such as restoring degraded dunes and/or implementing conservative set-back lines that reduce the risk of damage to human settlements and promotes conservation of the sandy beach ecosystem.

Of the top 10 most vulnerable beaches, half had non-native *Casuarina* trees present. Mamallapuram – Pondi beach (#126) and Nagapattinam (#29) have moderate nesting of *L. olivacea* and with non-native *Casuarina* trees comprising more than 25% along the backshore or dunes. Furthermore, non-native *Casuarina* occurrence is most common on *L. olivacea* study sites of the northwestern Indian Ocean (attributed to large scale plantations of *C. equisetifolia* on the Indian coastline), including Devi river mouth, where 150 000–200 000 female turtles nest (Shanker et al., 2004). This is of concern because *L. olivacea* populations of the west and north-east Indian Ocean are some of the least resilient/most vulnerable marine turtle Regional Management Units (RMUs). These *L. olivacea* populations were categorised as vulnerable to climate change because of rookery vulnerability (the likelihood of functional rookeries becoming extirpated) and non-climate related threats, such as fisheries, take, coastal development and pollution/pathogens (Fuentes et al., 2013). Staged *Casuarina* removal at least as far inland as turtles' nest, could be carefully considered by managers, especially on beaches where *L. olivacea* nest.

Even though *Casuarina* trees may not strongly impact nesting turtles through an erosion-vulnerability mechanism, there are other effects of these trees that need to be considered prior to planting bio-shields behind rookeries. Casuarinas have a number of adverse effects on beach-dune ecosystems such as an initial slow growth, but once established *Casuarina spp*. increase exponentially (Potgieter et al 2014a), replace and outcompete native plant species (Hardman et al., 2012, Patil et al., 2002). Over time, these species create sterile, acidic soils, that inhibits growth of other plants and alter faunal diversity (Mazzotto et al., 1981). Sea turtles use the backshore to nest close to, in or under vegetation where present (Hays et al., 1995). Vegetation then has a direct effect on the incubation environment and ultimately, hatchling sex ratios and hatchling success (Wood and Bjorndal, 2000). The effect of *Casuarina* trees on soil characteristics, such as pH (Batish et al., 2001) and temperature (Chaudari et al., 2009), or root proliferation into nests, may significantly change parameters required for successful egg incubation or hatching. Furthermore, the significantly lower temperature underneath *Casuarina* trees may have implications for sex ratios of sea turtle hatchlings (because sea turtles have temperature-dependent sex determination), with more males being produced in the presence of *Casuarina* trees (Chaudari et al., 2009). Furthermore, *Casuarina* roots do not retain sand, which alters sediment dynamics, and create steep shores (Chaudari et al., 2009; Sealy 2006). A toppled *Casuarina* tree can provide a physical barrier to female turtles as they haul up the beach to nest; and the root system can provide a barrier to females as they attempt to dig their nests. For example, Chaudari et al. (2009) highlighted the potential negative impacts of *Casuarina* trees on *L. olivacea* turtles along the Tamil Nadu coast, showing that fewer turtles nest in the presence of *Casuarina* trees.

The CVI method involved scoring a suite of indicators which provides a good regional overview of general patterns. There are some clear shortcomings though; Ideally, the CVI should be followed with quantitative, local-scale assessments (ideally with data from field surveys) to establish if *Casuarina* trees are contributing to erosion at smaller scales, serving also to ground-truth the results. In this case, there are several indicators that were omitted in our study due to data limitations at an ocean-basin scale, but that could be very informative in more detailed, local assessments. These include elevation (Kumar et al., 2010; Gornitz et al., 1994) and shoreline change (Thieler and Hammer-Klose, 2000; Boruff et al., 2005; Pendleton et al., 2010). We recommend including long-term data on these indicators because shoreline change gives a precise indication of whether a beach has been eroding or accreting (Corbella and Stretch, 2012) and elevation gives a good indication of a beach's ability to withstand or recover from episodic events (Abuodha, 2006). Future studies should also consider indicators that address the recovery potential of beaches. For example, Pethick and Crooks (2000) related disturbance-event frequency to relaxation time (the time taken for the littoral component to recover its shape), thereby providing an approximation of temporal variability of coastal features.

In conclusion: Research to date on the sustainability of using exotic *Casuarina* trees in coastal regions has demonstrated physical impacts on sandy beaches (Morton, 1980; Jadhav and Gaynar, 1995; Gordon, 1998; Batish et al., 2001; Patil et al., 2002; Sealey, 2006; Chaudari et al., 2009; Wheeler et al., 2011; Hardman et al., 2012). Non-native *Casuarina* were present on beaches in the IOSEA region, and planting these trees seems to be a popular management action. Although the regional CVI analysis did not show more vulnerability to erosion on beaches backed by *Casuarina*, it is important to recognise that these trees may pose other threats to nesting sea turtles. These threats include changing the nest-incubation environment, and serving as barriers to female turtles during nesting, especially if the trees have toppled over. Furthermore, the CVI was applied at an ocean-basin scale, and local-scale indicators and data may provide more refined insights on the effect of these trees on beaches. Therefore, managers and other decision-makers need to carefully consider the impacts of non-native *Casuarina* bio-shields before planting these trees, especially if the beaches are turtle rookeries, although compared to other threats this may be considered a low threat. In the IOSEA region, specific species such as *L. olivacea* rookeries seem more vulnerable to the impacts of *Casuarina*, and mitigation measures, such as staged removal of these trees, might be a prudent course of action. Planted casuarinas outside of their native range, may have economic benefits but the biodiversity benefits are limited. Maintaining and restoring intact dune cordons behind beaches has multiple benefits (e.g., protection for people and infrastructure, and conservation of ecological patterns and processes) and thus ultimately, implementing conservative setback lines is the most ideal approach to managing sandy shores. Idiosyncratic dune stabilization, specially using *Casuarina* trees, have more negative effects (e.g. interrupting sediment supply) that may have long-term, downstream effects which are not considered in evaluating short-term economic benefits.

Summarised from:

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APPENDIX 1: Site details

Site number	Site ID	Country	Beaches	X	Y	Species	SWOT report data	Year	Source	Casuarina present /absent
1	AU08	Australia	Bungelup	113.83083	-22.28139	*Cc*	659 females	2006	SWOT Vol II (2007)	Absent
2	AU10	Australia	Dayman Island	142.373	-10.7628	*Ei*	> 500 females	1997	SWOT Vol III (2008)	Absent
3	AU11	Australia	Hawkesbury (Warral) Island	142.126	-10.3812	*Ei*	> 500 females	1997	SWOT Vol III (2008)	Absent
4	AU119	Australia	Cemetery Beach	118.607987	-20.307638	*Nd*	750 clutches per year	2004 - 2007	SWOT Vol IV (2009)	Absent
5	AU15	Australia	Long Island	142.847	-10.0459	*Ei*	> 500 females	1997	SWOT Vol III (2008)	Absent*
6	AU27	Australia	Rosemary Island	116.585367	-20.472455	*Ei*	423 females	2006	SWOT Vol III (2008)	Absent
7	AU284	Australia	Cape Van Diemen	130.381	-11.1727	*Lo*	798 - 3812 females per year	2007	SWOT Vol V (2010)	Absent
8	AU300	Australia	Moulter Cay, north Great Barrier Reef	144.020251	-11.4099	*Cm*	2164 nests	2001	SWOT Vol VI (2011)	Absent
9	AU309	Australia	Raine Island, north Great Barrier Reef	144.033256	-11.590912	*Cm*	70122 females	2001	SWOT Vol VI (2011)	Absent
10	AU33	Australia	Woongarra coast including Mon Repos	152.441337	-24.795385	*Cc*	320 females	2005	SWOT Vol II (2007)	Present
11	AU34	Australia	Wreck Island	151.95718	-23.33325	*Cc*	62 females	2005	SWOT Vol II (2007)	Present
12	AU39	Australia	Cape Domett	128.409076	-14.80117	*Nd*	3250 clutches	2006	SWOT Vol IV (2009)	Absent
13	AU70	Australia	Crab Island	142.10236	-10.99022	*Nd*	1000 - 5000 females per year	2007	SWOT Vol IV (2009)	Present
14	AU71	Australia	Flinders Beach	141.73581	-12.218956	*Nd*	100 - 500 females per year	1990 - 2007	SWOT Vol IV (2009)	Absent*
15	AU80	Australia	Wild Duck	149.86037	-22.001724	*Nd*	> 100 females per year	2007	SWOT Vol IV (2009)	Absent*
16	AU81	Australia	Barrow Island	115.45887	-20.79204	*Nd* *Cm* *Ei*	1700 females	2005 - 2007	SWOT Vol IV (2009)	Absent
17	AU82	Australia	Mundabullangana Beach	118.0377	-20.4449	*Nd*	1600 females	1998 - 2007	SWOT Vol IV (2009)	Absent
18	BNX	Brunei Darussalam	Brunei	114.474096	4.679503	*Lo*	> 300 clutches	2003	SWOT Vol V (2010)	Present

19	ER01	Eritrea	Aucan Island	40.802591	15.510841	*Ei*	735 nests	2006	SWOT Vol III (2008)	Absent
20	ER02	Eritrea	Mojeidi Island	40.864905	15.502738	*Ei*	840 nests	2006	SWOT Vol III (2008)	Absent
21	ID02	Indonesia	Jamursba Medi	132.437701	-0.34792	*Dc*	3601 nests	2003	SWOT Vol I (2006)	Present
22	ID14	Indonesia	Warmon	132.807693	-0.421857	*Dc*	2881 nests	2004	SWOT Vol I (2006)	Absent
23	ID27	Indonesia	Bilang-Bilangan	118.9472	1.5611	*Cm*	4566 clutches	2010	OBIS-SEAMAP	Absent
24	IN02	India	Beaches straddling the Alexandria and Dagmar Rivers	93.693673	7.017542	*Dc*	1228 nests	2001	SWOT Vol I (2006)	Absent
25	IN04	India	Cuthbert Bay	92.967962	12.708577	*Lo*	711 clutches	2003	SWOT Vol V (2010)	Absent
26	IN05	India	Galathea Beach, Great Nicobar Island	93.852426	6.81737	*Dc*	574 nests	2004	SWOT Vol I (2006)	Absent
27	IN102	India	Kalingapatnam/Vamsadhara	84.12767	18.327816	*Lo*	570 clutches	2001	SWOT Vol V (2010)	Present
28	IN126	India	Mamallapuram - Pondi	80.197585	12.613229	*Lo*	600 clutches	2000	SWOT Vol V (2010)	Present
29	IN137	India	Nagapattinam	79.852646	10.712352	*Lo*	180 clutches	2000	SWOT Vol V (2010)	Present
30	IN180	India	Srikurmam	84.02962	18.25152	*Lo*	283 clutches	2001	SWOT Vol V (2010)	Present
31	IN200	India	Srikakulam	83.956863	18.220438	*Lo*	264 clutches	2001	SWOT Vol V (2010)	Present
32	IN76	India	Devi River mouth, Orissa	86.40603	19.98021	*Lo*	150 000 - 200 000 females	2003	SWOT Vol V (2010)	Present
33	LK02	Sri Lanka	Bentota	79.98471	6.446412	*Cm* *Lo* *Dc*	2 nests 40 nests Unquantified, but present	2014 2014 2003 - 2008	Jayathilaka et al. 2016 Jayathilaka et al. 2016 SWOT Vol I (2006)	Absent
34	LK05	Sri Lanka	Rekawa	80.823496	6.042668	*Cm* *Cc* *Dc* *Lo* *Ei*	752 females 6 females 28 females 38 females 3 females	1996 - 2000	Ekanayake et al. 2002	Present
35	LK21	Sri Lanka	Kosgoda	80.01823	6.35326	*Cm* *Cc* *Lo*	298 nests per year Unquantified, but present 400 clutches per year	2003-2008 1997	Ekanayake et al. 2011 SWOT Vol II (2007) SWOT Vol V (2008)	Absent
36	Murali_01	India	Gahirmatha	87.043	20.699747	*Lo*	Refer to Devi river mouth	2003	SWOT Vol V (2010)	Present
37	Murali_02	India	Rushikulya	85.085342	19.386358	*Lo*	Refer to Devi river mouth	2003	SWOT Vol V (2010)	Present
38	MY02	Malaysia	Turtle Islands, Sabah	118.024	6.1115	*Cm* *Ei*	8000 clutches	2000	SWOT Vol VI (2011)	Absent
39	MZ07	Mozambique	Malongane	32.892775	-26.770816	*Cc*	165 clutches	2009	OBIS-SEAMAP	Absent

40	OM02	Oman	Masirah	58.707774	20.208721	*Cc*	30 000 females	2007	SWOT Vol II (2007)	Absent
41	OM11	Oman	Dalmaniyat	58.067784	23.853392	*Ei*	1225 clutches	1986	OBIS-SEAMAP	Absent
42	OM12	Oman	Ras al Had	59.826	22.421	*Cm*	44 000 clutches	1985	SWOT Vol VI (2011)	Absent
43	PG02	Papua New Guinea	Busama (Buli)	146.94585	-6.92241	*Dc*	73 clutches	2012	OBIS-SEAMAP	Absent
44	PG04	Papua New Guinea	Kamiali Wildlife Management Area	147.12447	-7.285559	*Dc*	71 females	2004	SWOT Vol I (2006)	Absent
45	SC08	Seychelles	Cousin Island Special Reserve	55.662267	-4.330824	*Ei*	331 nests	2006	SWOT Vol III (2008)	Present
46	SC10	Seychelles	D’Arros Island and St. Joseph Atoll	53.29899	-5.415606	*Ei* *Cm*	250 - 300 females	2005	SWOT Vol III (2008)	Present
47	SC52	Seychelles	Farquhar Group	51.18627	-10.13623	*Cm* *Ei*	4145 females	2002	SWOT Vol VI (2011)	Present
48	TF03	French Southern Territories	Europa	40.3628	-22.35793	*Cm*	8282 crawls	2009	SWOT Vol VI (2011)	Present
49	YE01	Yemen	Abalhan Protected Area/Socotra Man and Biosphere Reserve	53.9219	12.5967	*Cc*	74 females	2005	SWOT Vol II (2007)	Absent
50	ZA01	South Africa	Mabibi to Kosi Lake/Bhanga Nek	32.805	-27.165	*Dc* *Cc*	112 nests 238 females	2004 2004 - 2005	SWOT Vol I (2006) SWOT Vol II (2007)	Present

* May have occasional *Casuarina* trees present.

APPENDIX 2: Normalised Risk and Threat Scores with the final Vulnerability Score per site. (* Indicate occasional *Casuarinas*)

Site	Site ID	Country	Beaches	Beach width	Exposure	Modal beach energy	Dunes	Summed Risk Score	Development	Sea level rise	Storm frequency	Storm intensity	Summed Threat Score	Casuarina pres /abs	*Species*	Vulnerability
1	AU08	Australia	Bungelup	1	0.38	0.38	0.33	2.08	0.0	0.20	0.1	0.6	0.95	Absent	*Cc*	3.03
2	AU10	Australia	Dayman Island	1	0.38	0.29	1.00	2.67	0.3	0.20	0.3	0.1	0.91	Absent	*Ei*	3.58
3	AU11	Australia	Hawkesbury (Warral) Island	0.4	0.25	0.42	1.00	2.07	0.0	0.20	0.3	0.1	0.58	Absent	*Ei*	2.64
4	AU119	Australia	Cemetery Beach	1	0.50	0.33	0.67	2.50	0.9	0.20	0.5	0.6	2.21	Absent	*Nd*	4.71
5	AU15	Australia	Long Island	1	0.38	0.42	1.00	2.79	0.0	0.20	0.3	0.1	0.58	Absent*	*Ei*	3.37
6	AU27	Australia	Rosemary Island	1	0.25	0.33	0.33	1.92	0.0	0.20	0.5	0.5	1.20	Absent	*Ei*	3.12
7	AU284	Australia	Cape Van Diemen	1	0.50	0.33	0.67	2.50	0.0	0.20	0.4	0.1	0.70	Absent	*Lo*	3.20
8	AU300	Australia	Moulter Cay, nGBR	0.2	0.25	0.46	1.00	1.91	0.0	0.40	0.3	0.1	0.78	Absent	*Cm*	2.68
9	AU309	Australia	Raine Island, nGBR	0.2	0.25	0.50	1.00	1.95	0.0	0.40	0.3	0.1	0.78	Absent	*Cm*	2.73
10	AU33	Australia	Woongarra coast + Mon Repos	0.8	0.50	0.38	0.67	2.34	0.0	0.60	0.1	0.4	1.10	Present	*Cc*	3.44
11	AU34	Australia	Wreck Island	1	0.25	0.42	1.00	2.67	0.0	0.60	0.3	0.5	1.35	Present	*Cc*	4.02
12	AU39	Australia	Cape Domett	0.8	0.88	0.33	0.67	2.68	0.0	0.20	0.4	0.1	0.70	Absent	*Nd*	3.38
13	AU70	Australia	Crab Island	0.2	0.25	0.33	0.83	1.62	0.0	0.20	0.3	0.1	0.58	Present	*Nd*	2.19
14	AU71	Australia	Flinders Beach	0.6	0.63	0.29	0.67	2.18	0.0	0.20	0.4	0.5	1.08	Absent*	*Nd*	3.26
15	AU80	Australia	Wild Duck	0.4	0.13	0.33	0.67	1.53	0.2	0.60	0.1	0.1	1.07	Absent*	*Nd*	2.60
16	AU81	Australia	Barrow Island	0.2	0.50	0.29	0.33	1.33	0.8	0.20	0.5	0.5	1.98	Absent	*Nd, Cm, Ei*	3.30
17	AU82	Australia	Mundabullangana Beach	0.8	0.63	0.29	0.33	2.05	0.0	0.20	0.5	0.6	1.33	Absent	*Nd*	3.38
18	BNX	Brunei Darussalam	Brunei	0.6	0.88	0.25	1.00	2.73	0.7	0.20	0.1	0.1	1.12	Present	*Lo*	3.84
19	ER01	Eritrea	Aucan Island	1	0.25	0.25	0.33	1.83	0.0	0.20	0.1	0.1	0.45	Absent	*Ei*	2.28
20	ER02	Eritrea	Mojeidi Island	1	0.38	0.25	0.33	1.96	0.0	0.20	0.1	0.1	0.45	Absent	*Ei*	2.41
21	ID02	Indonesia	Jamursba Medi	0.6	0.88	0.25	1.00	2.73	0.0	0.20	0.1	0.1	0.45	Present	*Dc*	3.18
22	ID14	Indonesia	Warmon	0.6	1.00	0.21	1.00	2.81	0.2	0.20	0.1	0.1	0.67	Absent	*Dc*	3.48
23	ID27	Indonesia	Bilang-Bilangan	1	0.25	0.25	1.00	2.50	0.2	0.20	0.1	0.1	0.67	Absent	*Cm*	3.17
24	IN02	India	Beaches at Alexandria and Dagmar Rivers	1	0.75	0.29	0.33	2.38	0.0	0.20	0.1	0.1	0.45	Absent	*Dc*	2.83

25	IN04	India	Cuthbert Bay	0.6	0.50	0.33	1.00	2.43	0.0	0.20	0.1	0.1	0.45	Absent	*Lo*	2.88
26	IN05	India	Galathea Beach, Great Nicobar Island	1	0.50	0.38	1.00	2.88	0.0	0.20	0.1	0.1	0.45	Absent	*Dc*	3.33
27	IN102	India	Kalingapatnam/Vamsadhara	0.2	0.63	0.38	0.67	1.87	0.7	0.20	0.4	0.3	1.49	Present	*Lo*	3.36
28	IN126	India	Mamallapuram - Pondi	0.6	0.88	0.29	1.00	2.77	0.6	0.20	0.3	0.5	1.51	Present	*Lo*	4.27
29	IN137	India	Nagapattinam	0.4	0.88	0.25	1.00	2.53	0.6	0.20	0.3	0.5	1.51	Present	*Lo*	4.03
30	IN180	India	Srikurmam	0.2	1.00	0.42	0.33	1.95	0.0	0.20	0.4	0.3	0.83	Present	*Lo*	2.78
31	IN200	India	Srikakulam	0.2	1.00	0.42	0.33	1.95	0.0	0.20	0.4	0.3	0.83	Present	*Lo*	2.78
32	IN76	India	Devi River mouth, Orissa	0.2	0.50	0.38	1.00	2.08	0.0	0.20	0.4	0.6	1.20	Present	*Lo*	3.28
33	LK02	Sri Lanka	Bentota	0.2	0.88	0.33	1.00	2.41	0.9	0.20	0.1	0.5	1.71	Absent	*Cm, Lo, Dc*	4.12
34	LK05	Sri Lanka	Rekawa	0.2	0.75	0.38	0.67	1.99	0.8	0.20	0.1	0.1	1.23	Present	*Cm, Cc, Dc , Lo, Ei*	3.22
35	LK21	Sri Lanka	Kosgoda	0.4	0.75	0.33	1.00	2.48	0.7	0.20	0.1	0.1	1.12	Absent	*Cm, Cc, Lo*	3.60
36	Murali_01	India	Gahirmatha	0.2	0.88	1.00	0.33	2.41	0.0	0.20	0.4	0.3	0.83	Present	*Lo*	3.23
37	Murali_02	India	Rushikulya	0.2	0.75	0.96	0.67	2.58	0.0	0.20	0.4	0.3	0.83	Present	*Lo*	3.40
38	MY02	Malaysia	Turtle Islands, Sabah	1	0.38	0.25	1.00	2.63	0.4	0.20	0.1	0.1	0.89	Absent	*Cm, Ei*	3.52
39	MZ07	Mozambique	Malongane	0.2	1.00	0.38	0.50	2.08	0.3	0.20	0.1	0.4	1.03	Absent	*Cc*	3.11
40	OM02	Oman	Masirah	0.2	0.50	0.42	0.33	1.45	0.7	0.20	0.1	0.5	1.49	Absent	*Cm*	2.94
41	OM11	Oman	Dalmaniyat	1	0.25	0.25	0.33	1.83	0.2	0.20	0.1	0.9	1.42	Absent	*Ei*	3.26
42	OM12	Oman	Ras al Had	0.2	0.50	0.29	0.33	1.33	0.4	0.20	0.1	0.9	1.64	Absent	*Cm*	2.97
43	PG02	Papua New Guinea	Busama (Buli)	1	0.75	0.21	1.00	2.96	0.0	0.20	0.1	0.1	0.45	Absent	*Dc*	3.41
44	PG04	Papua New Guinea	Kamiali Wildlife Management Area	1	0.63	0.21	1.00	2.83	0.3	0.20	0.1	0.1	0.78	Absent	*Dc*	3.62
45	SC08	Seychelles	Cousin Island Special Reserve	0.8	0.75	0.38	1.00	2.93	0.3	0.20	0.1	0.5	1.16	Present	*Ei*	4.08
46	SC10	Seychelles	D’Arros Island and St. Joseph Atoll	1	0.38	0.42	1.00	2.79	0.4	0.20	0.1	0.1	0.89	Present	*Ei, Cm*	3.69
47	SC52	Seychelles	Farquhar Group	0.8	0.13	0.46	1.00	2.38	0.3	0.20	0.5	0.1	1.16	Present	*Cm, Ei*	3.54
48	TF03	France	Europa	0.8	0.25	0.40	0.67	2.11	0.0	0.20	0.5	0.4	1.08	Present	*Cm*	3.19
49	YE01	Yemen	Abalhan Prot. A./Socotra Biosp. Res.	0.6	0.75	0.25	0.33	1.93	0.7	0.40	0.1	0.4	1.57	Absent	*Cc*	3.50
50	ZA01	South Africa	Mabibi to Kosi Lake/Bhanga Nek	0.4	1.00	0.38	0.50	2.28	0.4	0.20	0.1	0.4	1.14	Present	*Dc, Cc*	3.42