Chapter 20

A future for the dugong?

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Introduction

The dugong *(Dugong dugon)* is the only herbivorous mammal that is strictly marine and is the only extant species in the Family Dugongidae. The other members of the Order Sirenia, the three species of manatee, all use fresh water to varying degrees (Reynolds and Odell 1991). The only other recent Sirenian, Steller's sea cow, *Hydrodamalis gigas,* was hunted to extinction within 27 years of its discovery in the eighteenth century (Stejneger 1887). All extant members of Order Sirenia (including the dugong) are listed as vulnerable to extinction (Hilton-Taylor 2000). All populations of the dugong are also listed on Appendix 1 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Prospects for the survival of the dugong are the best among the Sirenia, because each manatee species has a more localized distribution than that of the dugong (Reynolds and Odell 1991). In addition, the estimates of dugong abundance in Australia which total to a mean of about 85,000 individuals (Marsh *et al*. 1999) are much greater than have been recorded or suggested for any species of manatee.

The dugong has a large range (Figure 1) that spans at least 37 countries and territories and includes tropical and subtropical coastal and island waters from east Africa to Vanuatu, between about 26^{o} and 27^{o} north and south of the equator (Nishiwaki and Marsh 1985). The dugong's historic distribution is believed to have been broadly coincident with the tropical Indo–Pacific distribution of its food plants, the phanerogamous seagrasses of the families Potamogetonaceae and Hydrocharitaceae (Husar 1978). The dugong is at risk from unsustainable mortality because of its low intrinsic rates of population increase and to habitat loss because of its specialist coastal habitat requirements. Australia is recognised as the dugong's stronghold and it is generally believed that throughout much of the remainder of its range, the dugong is represented by relict populations separated by large areas where its numbers have been greatly reduced or it is already extirpated (Marsh & Lefebvre 1994). However, the degree to which dugong numbers have dwindled, and their range fragmented, is not known for any country in its range. In this paper, we evaluate the dugong's prospects and tentatively conclude that they are spatially variable. It is at risk of extinction in some parts of its range, its prospects are uncertain in others, and its prospects are reasonable, at least for the next few decades, in the Red Sea and most of its range in Australia.

Methods

This evaluation is based on published information and the expert opinions of about 100 scientists and managers. These people were generally contacted by email using a snowball sampling technique between 1997 and 2001 as part of the process leading to the development of a global status and action plan for the dugong (Marsh *et al.* 2002). All information supplied was reviewed by more than 60 in-country experts who were asked to comment on the text that we developed based on the information supplied. Using this technique, we obtained information on dugong distribution and abundance, status, threats, and research and conservation actions in 37 countries and territories in the dugong's known range as listed in Table 1. We were unable to obtain any information from Myanmar (Burma). The information in this paper is a synthesis of the material obtained using this technique. The information is presented in more detail in Marsh *et al.* (2002).

Biological context

Like other marine mammals, dugongs have evolved anatomical, physiological and life history adaptations to the marine environment including a large body size and a long lifespan. They tend to mature late, have a single offspring at intervals of several years and have low natural mortality rates, living for 70 years or more (Marsh 1999). The other reason why the dugong is vulnerable to extinction is that it is a seagrass specialist and thus has to feed in restricted habitat in coastal waters. The species for which mortality is most likely to be unsustainable have low intrinsic rates of population increase and little resilience in their population dynamics (Caughley 1994).

Those most susceptible to habitat loss have specialist habitat requirements and no alternatives for foraging. The dugong, like other large mammals with low reproductive output and specialist habitat requirements, is vulnerable for both reasons.

Life History

Almost all information on dugong life history has been obtained from the analysis of animals accidentally drowned in shark nets or killed by native hunters in northern Australia. The age-determination method developed for pinnipeds and toothed cetaceans was adapted for dugongs enabling their age to be estimated from the number of growth layer groups in the tusks (see Marsh 1980). Life-history parameters are summarized in Marsh (1995a, 1999; Kwan, 2002). Dugongs are long-lived with a low reproductive rate, long generation time, and a high investment in each offspring. The oldest dugong whose tusks have been examined for age determination was estimated to be 73 years old when she died. Marsh's research suggests that females do not bear their first calf until they are at least ten and up to 17 years old. Using the same age determination technique, Kwan (2002) has recent evidence from Torres Strait of dugongs producing their first calf as early as age 6 years. Gestation lasts about 13-15 months. The usual litter size is one. The calf suckles for 14-18 months or so, and the period between successive births is spatially and temporally variable; estimates range from 2.4 (Kwan 2002) to seven years. Dugongs start eating seagrasses soon after birth, but they grow rapidly during the suckling period when they also receive milk from their mothers. The spatial and temporal variation in their life history parameters is most likely a response to variation in seagrass community composition and biomass (Marsh 1999; Kwan 2002). Population simulations indicate that even with the most optimistic combinations of life-history parameters (e.g., low natural mortality and no human-induced mortality) a dugong population is unlikely to increase more than 5% per year (Marsh 1995a, 1999; Kwan 2002).

Diet

Dugongs uproot whole seagrass plants when they are accessible, but feed only on leaves when the whole plant cannot be uprooted (Anderson 1982a; Marsh et al. 1982, 1999). Anderson (1998) observed dugongs foraging in North Cove, Shark Bay, Western Australia. He concluded that dugongs selectively forage for Halodule rhizomes in that area. Dugongs prefer seagrasses that are lower seral or ‘pioneer’ species (Preen and Marsh 1995), especially species of the genera Halophila and Halodule. Diet selection is correlated with the chemical and structural composition of seagrass (Lanyon 1991; Aragones 1996). The most frequently selected species are lowest in fibre and highest in available nitrogen and digestibility (Lanyon 1991; Aragones 1996). Selection for species that are highly digestible (Halophila) and have high nutrients (Halodule) means that dugongs maximize the intake of nutrients rather than bulk (Aragones 1996). Marine algae are also eaten (Marsh et al.1982), but this is believed to occur only when seagrass is scarce (Spain and Heinsohn 1973). Anderson (1989) and Preen (1995a) have evidence that dugongs may deliberately forage for macro-invertebrates near the southern limits of their range in both western and eastern Australia. However, examination of stomach and faecal samples (Preen and Marsh 1995) suggests that dugongs do not deliberately forage on macro-invertebrates in more tropical areas of Australia. This conclusion must be regarded as tentative because of the differential digestibility of plant and animal material in the mammalian alimentary canal.

The highly specialized dietary requirements of the dugong suggest that only certain seagrass meadows may be suitable as dugong habitat (Preen et al. 1995). Preen et al. (1995), de Iongh (1996a and b) and Aragones and Marsh (2000) suggest that grazing activities by dugongs alter the species composition of seagrass communities at a local scale. Preen (1995b) coined the term ‘cultivation grazing’ to describe the capacity of intensive grazing by dugongs to alter the to alter the species composition of seagrass meadows in favour of rapidly growing, early pioneer species of seagrass such as Halophila ovalis, which are favoured by dugongs, at the expense of slower growing but dominant species such as Zostera capricorni, which are less preferred. Thus areas that support sizeable numbers of dugongs may have the capacity to provide better ‘quality’ food than areas that support few or no dugongs and rely only on natural turnover rates for recycling and redistribution of nutrients (Aragones and Marsh 2000). Studies of dugong grazing in Thailand (Supanwanid, 1996) and Indonesia (de Iongh et al.,1998), where dugong densities tend to be low, have generally supported the results of the Australian studies cited above, which have been conducted in areas of relatively high dugong density.

Habitat

Dugongs generally frequent coastal waters. Major concentrations tend to occur in wide shallow protected bays, wide shallow mangrove channels and in the lee of large inshore islands (Heinsohn *et al.* 1979). These areas are coincident with sizeable seagrass beds. Dugongs are also regularly observed in deeper water further offshore in areas where the continental shelf is wide, shallow and protected. For example, in Torres Strait between Australia and Papua New Guinea, significant numbers of dugongs are seen more than 10km from land (Marsh and Saalfeld 1989, 1991). Marsh and Saalfeld (1989) have also sighted dugongs ~58km from the north Queensland coast, in water up to 37m deep. This distribution reflects that of deepwater seagrasses such as *Halophila spinulosa* (Lee Long *et al.* 1993). Dugong feeding trails have been observed at depths of up to 33m off northeastern Queensland (Lee Long *et al.* 1996). Whiting (1999) reported dugongs including calves at Ashmore Reef (12^{o} 15'S, 123^{o} 05'E) on the Sahul Banks on the edge of the Australian continental shelf. Although Ashmore Reef is only 140km from the Indonesian Island of Roti, the 2000m deep Timor Trough separates these locations. There is evidence that dugongs use specialised habitats for various activities. Shallow waters, such as tidal sandbanks (Marsh *et al.*1984) and estuaries (Hughes and Oxley-Oxland 1971), have been reported as sites for calving. Anderson (1981) suggested that this could be a strategy to minimise the risk of shark predation. At the higher latitudinal limits to their range in winter, dugongs may use deeper waters as a thermal refuge from cooler inshore waters (Anderson 1986; Marsh *et al.* 1990; Preen 1992).

Movements

Most movements of the more than 60 dugongs that have been tracked by means of VHF or satellite transmitters in Indonesian and Australian waters have been localised to the vicinity of seagrass beds (Marsh and Rathbun 1990; Preen 1992; de Iongh 1996b; de Iongh et al. 1998; Preen 1999, 2001). Animals caught in the same locality tend to show individualistic patterns of movement. Daily movements depend on tidal amplitude. At localities where the tidal range is large, dugongs can gain access to their inshore feeding areas only when water depth is deeper than about 90cm. In areas with low tidal amplitude (Anderson 1982b) or in areas where seagrass grows subtidally, daily movements are not dictated by tides. At the high-latitude limits of their range, dugongs make seasonal movements to warmer waters. In winter in Moreton Bay Queensland, dugongs regularly make a round trip of 15–40km between their foraging grounds inside the bay and oceanic waters, which average up to 5^{o}C warmer (Preen 1992). Dugongs also undertake winter movements of the order of 100km across Shark Bay in Western Australia to warmer waters in the westward part of that bay (Anderson 1982b, Marsh et al. 1994; Gales, Holly and Lawler unpublished data). At least some individual dugongs of both sexes undertake long-distance movements. An adult female moved 400km between two sites in the Gulf of Carpentaria in Australia over about five days (Preen 1995c). Another male travelled between two localities, in the Central Section of the Great Barrier Reef Australia, a straight-line distance of 140km, three times in six weeks (Marsh and Rathbun 1990). Of the ten dugongs fitted with satellite transmitters in Shoalwater Bay, Queensland by Preen (1999), four made substantial trips out of that bay. Two made return trips: one 100km north, the other 220km north. Two other animals journeyed 400km south to Hervey Bay where their transmitters detached. Thirteen dugongs were tracked between the Townsville and Hinchinbrook Island region in Queensland. Twelve trips were made of more than 30km beyond the area regularly used by these animals, six trips of more than 100km and one trip of more than 600km (Preen 2001). Most of these movements were return trips. For example, the animal that moved more than 600km north returned to her capture point after five months and almost immediately moved another 165km south along the coast. The movements of this dugong thus spanned about 800 km of coast. Recent reports of dugongs at Aldabra Atoll (Chong-Seng pers comm. 2001), which is 425km from Madagascar, confirm their capacity to cross deep ocean trenches (up to 4km in depth) as dugongs have not been seen in this region for many years (Cockcroft et al. 1994; Cockcroft and Young 1998). This capacity of dugongs to undertake long-distance movements across oceanic waters indicates: (1) a potential for recruitment to regions where dugongs have been extirpated, and (2) that the management of dugongs is an international issue in most parts of their range (Figure 1).

Genetic Population Structure

Molecular techniques are being used to investigate the genetic population structure of dugongs (Tikel 1998; McDonald *pers comm.*). Results to date are based on mitochondrial DNA that evolves relatively quickly and is considered a good index of population structure. It is transmitted only in the female lineage and can only be used to estimate female-mediated gene flow. Results are based on very small sample sizes from outside Australia and for many areas in the dugong's range within Australia. In addition, male-mediated gene flow is often markedly greater than female-mediated flow in mammals. To test for this in dugongs, McDonald (*pers comm.*) has developed microsatelitte markers, which she is using to make a more complete assessment of the genetic population structure. Thus the conclusions outlined below are tentative.

The results suggest that the haplotypes of dugongs from parts of Southeast Asia (Indonesia, Thailand and the Philippines) are generally distinct from those from Australia with overlap at Ashmore Reef between Western Australia and Timor, suggesting that there is (or has been in the past) limited genetic exchange between Australia and Asia. The genetic structure of dugong populations around the Australian coast appears to comprise two maternal lineages (Tikel 1998, McDonald *per comm.*), which may reflect the history of sea level changes on the Australian continental shelf.

Threatening processes

Dugongs are vulnerable to anthropogenic influences because of their life history and their dependence on seagrasses that are restricted to coastal habitats, and often under pressure from human activities. As for other marine mammals, the pressures on dugongs have changed over time. In the past the major pressures on dugong populations were for their involved consumptive use for food and oil. Many modern pressures stem from the increase in the world's human population, particularly that proportion of the population living in the coastal zone. As the human population increases in coastal areas, so does pressure on coastal ecosystems through habitat loss and change, increased pollution, and demand for coastal resources. Globally, 50% of people live within 60km of the coast. It is likely that this will increase to 75% by 2020 (Intergovernmental Panel on Climate Change in DeMaster *et al.* 2001). The situation in developing countries has exacerbated by the displacement and urbanisation of rural human populations, which has led to the loss of traditional values and taboos to resource exploitation. The provision of aid from ‘developed countries’ has increased the efficiency and level of exploitation of coastal resources from uncontrolled development, open resource fishing, tourism, etc. often without adequate legislation, enforcement and management. Coastal development is listed as a problem for the dugong in 29 of the 37 countries and territories for which we have information (Table 2). The other major group of increasingly adverse impacts on dugongs derives from the growth of and technological advances in the world’s fishing industry. In the last 50 years marine fisheries production has increased more than fourfold. Fisheries impacts are seen as a problem in at least 35 of the 37 countries and territories for which we have data (Table 2). The major impact of fisheries on dugongs throughout their range results from their being caught as by-catch, especially in gill nets.

As for other long-lived species, the rate of population change of the dugong is most sensitive to changes in adult survivorship. Even a slight reduction in adult survivorship as a result of habitat loss, disease, hunting or incidental drowning in nets, can cause a chronic decline in a dugong population. As explained above, Marsh (1995a, 1999) suggested that the maximum rate of increase under optimum conditions would be on the order of 5% per year even when natural mortality is low (<5% per year). The sustainable harvest is likely to be in the order of 2% of the female population per year. The sustainable harvest rate will be lower in areas where the pre-reproductive period and/or calving interval are lengthened by food shortage (Marsh 1999). Dugongs may be short of food for several reasons including habitat loss, seagrass dieback, decline in the nutrient quality of available seagrass, or a reduction in the time available for feeding because of acoustic disturbance such as boat traffic.

Habitat Loss and Degradation

Seagrass ecosystems are very sensitive to human influence (Fonseca 1987; Shepherd *et al.* 1989; Poiner and Peterken 1996). Seagrass beds may be destroyed directly by mining, destructive fishing such as trawling, and boat propellers (Silas and Bastion-Fernando 1985), or lost through the effects of disturbances such as dredging, inland and coastal clearing, and land reclamation (Table 2). These activities cause increases in sedimentation and turbidity that, in turn, lead to degradation through smothering and lack of light. Other threats include sewage, detergents, heavy metals, hypersaline water from desalination plants and other waste products. Most losses, both natural and anthropogenic, are attributed to reduced light intensity due to sedimentation and/or increased epiphytic growth caused by nutrient enrichment. In some cases, factors such as poor catchment management and sediment instability interact to make the processes more complex so that it is often difficult to separate natural and anthropogenic causes of seagrass loss. In addition, herbicide runoff from agricultural lands also presents a potential risk to seagrass functioning adjacent to sugarcane production areas (Haynes *et al.*1998).

Episodic losses of hundreds of square kilometres of seagrass are associated with extreme weather events such as some cyclones, hurricanes and floods (Poiner and Peterken 1996). Jones (1967) reported the widespread loss of seagrass in the Gulf of Mannar–Palk Bay area between India and Sri-Lanka in 1954 as a result of a cyclone accompanied by very heavy rains. Large numbers of dugongs were reported to have washed ashore after the cyclone, presumably as a result of an accompanying storm surge as occurred in the Gulf of Capentaria in Northern Australia in 1984 (Marsh 1989). In the Gulf of Carpentaria, in 1985, cyclone Sandy caused the loss of 151km^2 of seagrass, representing ~20% of the Gulf's entire seagrass area. In 1991–92 several hundred square kilometres of seagrass disappeared from Torres Strait between Australia and Papua New Guinea, possibly because of high turbidities resulting from flooding of river(s) in Papua New Guinea (Poiner and Peterkin, 1996). Furthermore, more than 1000km^2 of seagrass were lost in Hervey Bay, Queensland in 1992–93, possibly because of high turbidities resulting from flooding of local rivers, and runoff turbulence from a cyclone three weeks later (Preen and Marsh 1995). Such events can cause extensive damage to seagrass communities through severe wave action, shifting sand, adverse changes in salinity and light reduction (Heinsohn and Spain 1974; Kenyon and Poiner 1987; Preen and Marsh 1995; Preen *et al*. 1995). Recovery and recolonisation after large-scale losses of tropical seagrasses may take up to a decade or more (Poiner and Peterken 1996).

Halophila ovalis, one of the preferred food species of dugongs, appears to be particularly sensitive to light reduction, with the duration and frequency of light-deprivation events apparently being the primary factors affecting the survival of this seagrass in environments that experience transient light deprivation (Longstaff *et* *al*.1999). During light-deprivation experiments the biomass of *H. ovalis* declined rapidly and recovered slowly, with a complete die-off occurring after 30 days of deprivation (Longstaff *et al.* 1999). Members of the genus *Halophila* occur at greater depths than other species of tropical seagrasses and this sensitivity to light reduction is a plausible explanation of the large-scale loss of deep-water seagrasses in Torres Strait (Poiner and Peterken 1996) and Hervey Bay in Queensland, Australia (Preen *et al*. 1995).

Dugongs seem to respond in one of two ways to large-scale seagrass loss. Some animals remain in the area, others move hundreds of kilometres. For example, after the loss of seagrass in Hervey Bay in 1992, a total of 99 dugong carcasses was recovered in the Hervey Bay area, on the central and southern Queensland coast and along the New South Wales coast (Preen and Marsh 1995). Most animals appeared to have died of starvation. Large-scale episodic loss of seagrass is the most plausible reason for the extensive large-scale movements of dugongs, which have been observed in Queensland and Western Australia by the long-term time-series of aerial surveys that have been conducted in these areas (see Marsh and Lawler 2002 for details).

To date, the approach to seagrass protection has largely been through marine parks and fishing industry closures to prevent structural damage to seagrass beds through trawling. There have been few attempts to protect seagrass beds from adverse impacts on ecosystem processes associated with land use, even though such impacts have been recorded as of concern in most of the countries in the dugong's range for which information is available (Table 2). Localities that provide shelter and water conditions ideal for seagrasses are often the target for port developments and at the down-stream end of severely affected catchments (Lee Long and Coles 1997).

Fishing Pressures

Accidental entangling in gill and mesh nets or traps set by fishers is considered a major, but largely unquantified, cause of dugong mortality in many countries (Perrin *et al.* 1996) and was identified as a major concern in virtually all countries for which we have information (Table 2). Throughout most of the dugong's range, this pressure comes from locally based artisanal fisheries. Of more concern, are the industrial scale gill net fisheries that have developed in some areas. Fortunately for dugongs, these are in offshore waters that are not major dugong habitats. To our knowledge, the systematic collation of data on the incidence of dugong by-catch in fisheries has not been attempted by observer programs in any country within the dugong's range. No data are available on the take of dugongs by lost or discarded nets, although drowning in these nets presumably occurs. The relationship between tides, bottom topography, turbidity and patterns of netting needs investigation. In relatively shallow bays with large tidal fluctuations and high turbidity, seagrass meadows are largely intertidal. In such conditions, dugongs and netters are all forced to use intertidal areas on the high tide, increasing the chances that dugongs will be caught.

Acoustic alarms (pingers) are proving effective at reducing the mortality of the harbor porpoise, *Phocoena phocoena*, in gill nets (Trippel *et al*. 1999). These alarms are increasingly seen as a possible solution to the problem of marine mammals drowning in nets in developed countries, although the associated costs are likely to preclude their use throughout most of the dugong's range. The auditory capabilities of the West Indian manatee range from 0.4 to 46 KHz (Gerstein *et al*. 1999), spanning the range of acoustic alarms (10–12 kHz) (Trippel *et al.* 1999). Amanda Hodgson (*pers comm*.) experimentally tested the behavioural response of dugongs to acoustic alarms and observed no change in their behaviour suggesting that these alarms would not prevent dugongs from being caught in nets.

Shark nets set for bather protection can be another source of dugong mortality. Between 1962 and 1995, shark nets set on swimming beaches in Queensland, Australia caught 837 dugongs (Anon. 1992). Most animals caught in shark nets die (Paterson 1990). In response to a Ministerial Committee of Enquiry (Anon. 1992), initiatives were begun in1992 (Gribble *et al*. 1998) to reduce the capture of non-target species. Baited hooks have replaced shark nets in many localities and the mortality associated with this program is now low
(Marsh *et al.* 2001).

Indigenous Use and Hunting

Dugongs are culturally significant to communities throughout their range. Marsh *et al.* (2002) obtained evidence of the indigenous use of dugong products in most of the 37 countries for which they were able to obtain information (Table 2). Dugongs are still caught for meat, oil, medicaments, amulets and other products. In many countries, dugong hunting is now banned and animals are no longer hunted deliberately. However, dugong products from indirect takes are still highly valued. Australia's indigenous peoples consider dugong hunting to be an important expression of their identity. In the Western Islands of Torres Strait, the dugong harvest in the 1990s was estimated to be on the order of 1000 per year (Marsh *et al*. 1997a); the long-term sustainability of this harvest has been questioned (Marsh *et al*. 1997b). The Torres Strait Treaty between Australia and Papua New Guinea explicitly protects the traditional way of life of the local indigenous peoples including the right to hunt dugongs. Fortunately, many communities in this region are now expressing a strong desire to develop dugong hunting management plans.

Vessel Strikes

Vessel strikes are a major cause of mortality for Florida manatees (Wright *et al.* 1995). Although manatees possess the intellectual and physical ability to recognise and avoid boats (Hartman 1979; Gerstein 1994, 1995), the results of Gerstein *et al*. (1999) suggest that the West Indian manatee possesses a limited low-frequency hearing sensitivity and therefore has difficulty detecting and locating approaching boats from safe distances. The relevance of these results to dugongs is unknown because the anatomy of the dugong ear differs from that of the manatee (Ketten *pers comm.* 2001). However, preliminary results from a study monitoring the reactions of dugong to boats from an aerostat-mounted video camera indicate that dugongs do not react to an approaching boat until it is almost on top of them (Hodgson *pers comm.* 2002). Although there are few documented dugong deaths due to vessel strikes (Table 2), increasing vessel traffic in the dugong's range increases the likelihood of strikes. Areas where there are extensive shallow areas used by dugongs close to areas of high boat traffic are particularly at risk.

Ecotourism

The expansion of ecotourism has resulted in the establishment of operations involving dugong-watching cruises at several locations in Australia and swim with dugong operations in the Philippines and Vanuatu (Marsh *et al*. 2002). The effects of these activities on the animals are unknown, although they area under investigation in Western Australia. We are unaware of similar operations outside these regions. Vessel-strikes and the alienation of dugongs from key habitats as a result of harassment are possible adverse impacts from ecotourism.

Acoustic Pollution

Despite consistent anecdotal reports of dugongs ceasing to use areas with high boat traffic, the only experimental study suggests that dugongs are not displaced from an area by repeated passes boats (Hodgson *pers comm*. 2002).

Defence force exercises are conducted at several localities within the dugong's range in Australia. We have no information from other countries. The exercises include surface and underwater explosion of bombs, amphibious landings, and firing of shells (Anon.1997). There have been no reports of dugong mortality as a direct result of these undersea detonations. Nonetheless, such explosions have the potential to cause indirect effects to the dugong such as injury, social disturbance, displacement or habitat damage (Anon. 1997). The risk of adverse effects on dugongs from defence force activities must be evaluated in the context of the reduction of other impacts as civilians are usually banned from defence areas.

Seismic surveys are an essential component of offshore oil and gas exploration and are used to study rock strata below the sea floor. Marine seismic surveys use high-energy, low frequency sound produced by arrays of air guns (Richardson *et al.* 1995) that are designed to project very strong sounds downward through the water column. Considerable sound propagates horizontally as well (Richardson and Malme 1993). The sounds produced by air-gun arrays have most of their energy in the frequency range of 10–100 Hz. Some specialized surveys may have energy in the 500 Hz to 2kHz range (McCauley *pers comm.* 2000), close to the frequency of sounds made by dugongs (Anderson and Barclay 1995). Effects might include: (1) interference with the animal's natural acoustic communication signals, (2) damage to their hearing systems, and (3) behavioural changes including disturbance reactions, ranging from brief alterations in behaviour to short- or long-term effects on individuals or populations (Richardson and Malme 1993; McCauley 1994). Although to date there has been no documented evidence of marine seismic surveys being detrimental to populations of dugongs, there have also been no detailed studies.

Chemical Pollutants

Dugongs accumulate high levels of some heavy metals with age (Miyazaki *et al.* 1979; Denton *et al.* 1980; Haynes 2001). There is no evidence to suggest that the accumulation of heavy metals is unnatural or particularly harmful to dugongs, as it appears to be a response to the manner in which seagrasses store these minerals. However, metal levels can be so high that some dugong tissues may be unsuitable for human consumption. Elevated concentrations of chromium and nickel have been detected in liver samples from several animals collected from the southern Queensland coast (Haynes 2001). Where ports are established to load metal ores in areas with significant populations of both dugongs and indigenous hunters, this issue requires consideration in the design and operation of storage and loading facilities.

The information on pesticide accumulation in dugongs is very limited and restricted to South Sulawesi (Miyazaki *et al.* 1979) and to northern Australia (Haynes 2001) where human population density is generally low. Tissue samples of liver and blubber were salvaged from 53 dugong carcasses stranded along the Queensland coast between 1996-2000 as part of the Necropsy Program coordinated by the Queensland Parks and Wildlife Service. Blubber samples were analysed for organochlorine compounds and polychlorinated biphenyls (Haynes 2001). Dieldrin, DDT and/or DDE were detected in 59% of blubber samples. Concentrations of these organochlorines were similar to those reported from dugongs 20 years earlier, and were low in comparison to concentrations recorded from marine mammal tissue collected elsewhere in the world. Polychlorinated dibenzodioxins appear to be the most significant organochlorine pollutant bioaccumulated in the dugong (Haynes *et al.* 1999). Necropsy sampling has determined that octachlorinated dibenzodioxins concentrations are up to twice as high in dugongs as has been reported from any other marine mammal (Haynes *et al.* 1999; McLachlan *et al.* 2001). Organochlorine pesticides and polychlorinated biphenyl congeners have been implicated in reproductive and immunological abnormalities observed in other marine mammal populations (Kuiken *et al.* 1994; Johnston *et al.* 1996). The significance of their occurrence in dugongs is unknown. Nonetheless, these results suggest that chemical pollution should be investigated in the more highly populated regions typical of the dugong's range outside Australia.

Even though dugongs occur in areas that are important shipping lanes, there is limited information about dugongs being impacted by oil spills. At least 37 dugong carcasses were recovered in the months after the Nowruz oil spill in the Arabian Gulf in 1983 (Preen 1989). Although the link with the oil spill was unproven, there is no evidence that another cause was responsible.

Status

Range

Dugongs are still present at the historical limits of their range (Figure 1), although there is evidence of a reduction in the dugong's area of occupancy within this range. For example, dugongs are now considered to be extinct in the Maldive and Laccadive Islands (Husar 1975). Nonetheless, recent fixed-wing aircraft and helicopter surveys have confirmed that dugongs still occur in two areas where they had been presumed to be locally extirpated: Ryukyu Islands in southwestern Japan (Kasuya *et al*. 2000) and in Peninsular Malaysia (Marsh *et al.* 2002). As mentioned above, there are also recent reports of dugongs at Aldabra Atoll (Chong-Seng *pers comm.* 2001).

Abundance

We consider that it is likely that dugong numbers are higher than previously supposed in many areas. For example, following the death of at least 37 dugongs during the 1983 Nowruz oil spill, it was feared that dugongs might have been extirpated from the Arabian Gulf. Aerial surveys in the region established that these fears were unjustified and that the estimated Arabian Gulf population was 7307+ s.e. 1302 (Preen 1989). In most of the 37 countries and territories in the dugong's range for which we have any information, our knowledge of their distribution and abundance is known only from incidental sightings, strandings, and the anecdotal reports of fishers (Table 1). In another 13 countries, the dugong is known only from spatially and temporally limited surveys generally conducted parallel to the shoreline. These surveys provide minimum counts only.

Extensive quantitative aerial surveys using transects across the shoreline depth gradient have resulted in a more comprehensive knowledge of dugong distribution and abundance in the coastal waters of most (but not all) of the dugong's range in the Arabian region (Preen 1989) and northern Australia (Marsh *et al*. 2002). However, even in these regions, the information is not comprehensive enough to establish trends in abundance for most areas, especially as there is increasing evidence that dugongs undertake large-scale movements at scales greater than those covered by individual surveys (even though the areas covered by these surveys is often very large - ~30,000km^2; Marsh and Lawler, 2002).

It is inappropriate to compare the abundance of dugongs estimated using shoreline and quantitative surveys. We believe that most of the estimates of dugong population size reported in Marsh *et al*. (2002) are underestimates, probably major underestimates. Nonetheless in most countries in its range, the anecdotal evidence suggests that dugong numbers are declining (Table 3). There is quantitative evidence of a decline on the urban coast of Queensland (Marsh *et al*. 2001), the part of the dugong's range in Australia where human population density in the coastal zone is highest. The amount of coastal development in this region contrasts with the general lack of development in the remote regions of Australia. Thus the quantitative evidence of decline along the urban coast of Queensland lends credibility to the anecdotal reports from other countries (Table 3) where human populations density in the coastal zone is even greater.

Overall Assessment

The degree to which dugong numbers have dwindled, and their range fragmented, is not known for any country in its range. On the basis of the largely anecdotal information supplied to us (Tables 1 and 3), we have evaluated the prospects of the dugongs' surviving throughout its range and tentatively conclude that:

- it is at risk of extinction in East Africa, India and Sri Lanka, Japan and Palau;
- its prospects are uncertain in the Arabian Gulf, East and South East Asia and the Pacific Islands;
- its prospects are probably reasonable in the Red Sea;
- it is probably secure in Australia, except in the urban coastal waters of Queensland.

The basis for this assessment is outlined in Table 3.

Approaches to Management

We believe that in view of the projected increase in the global human population especially in the coastal zone, it will be impossible to eliminate anthropogenic impacts on the dugong throughout its vast and often remote range. Detecting trends in dugong abundance, particularly at the low densities characteristic of most of this range, is very difficult – probably impossible (Marsh 1995b). Thus the objectives of maintaining dugong numbers at present or higher levels and facilitating the recovery of depleted populations will not be achieved if the only trigger for management intervention in an area is a demonstratively declining population. As pointed out by Wade (1998), it is often potentially easier to detect the circumstances that are likely to lead to a decline in the abundance of a marine mammal than it is to detect a decline *per se*. Methods have been developed in the USA (Wade 1998) for identifying populations of marine mammals with levels of human-caused mortality that could lead to depletion, taking account of the uncertainty of available information. Unfortunately, this technique cannot yet be used reliably to assess the status of the dugong, because we do not yet have the data required in estimating the necessary parameters. Once these data are available, the technique should have application in remote areas in northern Australia where indigenous hunting is the major adverse impact and the dugong harvest can be recorded. Unfortunately, this approach is likely to have limited application in most of the rest of dugong’s range where there are multiple adverse effects on dugongs. This is because of the difficulties of reliably detecting and estimating mortality in such circumstances, especially incidental mortality.

Legislation

Dugongs are protected from direct mortality by legislation in 17 countries (Table 1). However, in many areas this legislation is not policed and has limited effect. In addition, such protection generally addresses only one of the threatening processes discussed above.

Marine Protected Areas

A survey by the World Resources Institute rates the risks from coastal development as medium to high for much of the dugong's range outside Australia (Anon. 1996) because of high levels of human population growth and rapid rates of industrialisation. The dugong is also subject to indirect fishing mortality throughout most of this range (Perrin *et al*. 1996) (Table 2). The other threatening processes discussed above are also widely distributed (Table 2). In view of these multiple impacts, we consider that the optimum conservation strategy is to: (1) identify areas that still support significant numbers of dugongs; and (2) consider with extensive local involvement how impacts on dugongs can be minimised and the habitat protected in these key habitat areas.

Marine protected areas are increasingly important tools for marine conservation. They are established for a variety of purposes including fisheries management and the conservation of biodiversity and threatened species, such as the dugong. In our opinion, the protection of animals such as the dugong is most effective if sanctuary areas are embedded in a more broadly based system of ecologically representative areas such as is being done in the Great Barrier Reef World Heritage Area of Australia (Day *et al.* in press). Ideally, protection should also be developed in the context of comprehensive plans for management of the coastal zone (to reduce the risk of pollution from terrestrial runoff), perhaps using the dugong as a 'flagship species'. Marine protected areas work only if the local communities support them and if there are funds for enforcement. Far too many of the protected areas established to date are ineffective 'paper parks' e.g. the dugong sanctuary in Torres Strait (Marsh *et al*., 1997a).

Dugong protection may occur within designated marine protected areas in 14 countries throughout its known range. In addition, sanctuary areas have been established specifically to protect dugongs from particular impacts in Thailand, Papua New Guinea and Australia (Marsh et al. 2002). For example, the Queensland Government has established 4650km2 of Dugong Protection Areas to reduce the risk of dugongs drowning in gill nets (Marsh 2000).

The establishment of areas as dugong sanctuaries should reduce dugong mortality provided the areas chosen consistently support high numbers of animals, even though individual dugongs will move in and out of these areas (Marsh *et al.* 1999; Marsh 2000). The long-term effectiveness of these areas will depend on whether high-quality dugong habitat can be maintained. This will hinge to a large extent on the capacity to control land-based inputs. Candidate areas exist in much of the dugong's range and have been identified by Marsh *et al*. (2002). However, we acknowledge that in most situations there will be multiple demands on these areas necessitating complex tradeoffs, the solution to which will be location-specific. In all cases, it will be essential for the socio-economic impediments to dugong conservation to be addressed. Identifying important dugong habitats and securing their protection before local coastal development occurs is vital. Once land is purchased or developed, options become difficult and expensive (Reynolds *pers comm.* 2001).

Regional Co-operation

Given the difficulty of identifying stock boundaries and the capacity of dugongs to move across jurisdictional boundaries, it will be important to coordinate management initiatives across jurisdictions. The concept of a regional dugong workshop for Southeast Asia received wide support from international delegates at the workshop held in Davao City, Mindanao, in November 1998. Regional workshops would also be appropriate in many other parts of the dugong's range, such as East Africa, the Arabian region, the Indian sub-continent, and relevant island states in the Pacific Islands and Australia. The conservation of marine turtles and their habitats is specifically addressed in the Memorandum of Understanding on Indian Ocean and Southeast Asian Marine Turtle conservation and protection. The proposed Australian government initiative to enhance dugong conservation by promoting a similar regional agreement and conservation and management plan is welcome. Similar to marine turtles, dugongs have a priority for conservation action through their listing in the Convention on the Conservation of Migratory Species of Wild Animals (CMS). Developing a plan for dugongs similar to that already developed for Indian Ocean and Southeast Asian turtles should not be unduly difficult as the dugongs' distribution is similar to the area covered by the marine turtle agreement, and they share many overlapping conservation and management issues (which have are already been negotiated and agreed to in the marine turtle agreement). Therefore a well-established management group with international contacts and an agreed conservation and management plan is currently in place to negotiate and implement a regional agreement for dugongs.

The Importance of Australia

The challenge of managing adverse influences on dugongs in highly populated developing countries also confirms the importance of the remote regions of tropical Australia to dugong conservation. These regions not only support most of the world's dugongs but also have the advantage of a coastal zone that has a very low human population density. The importance of this region was emphasised by a workshop on the status of marine mammals in southeast Asia (Perrin *et al*. 1996). In this context, it is important that the agencies responsible for environmental management in the remote tropical regions of Australia outside the Great Barrier Reef region take a more pro-active and comprehensive approach to dugong conservation than they have attempted to date (Preen 1998).

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Legend to Figure

Figure 1. The known range of the dugong.

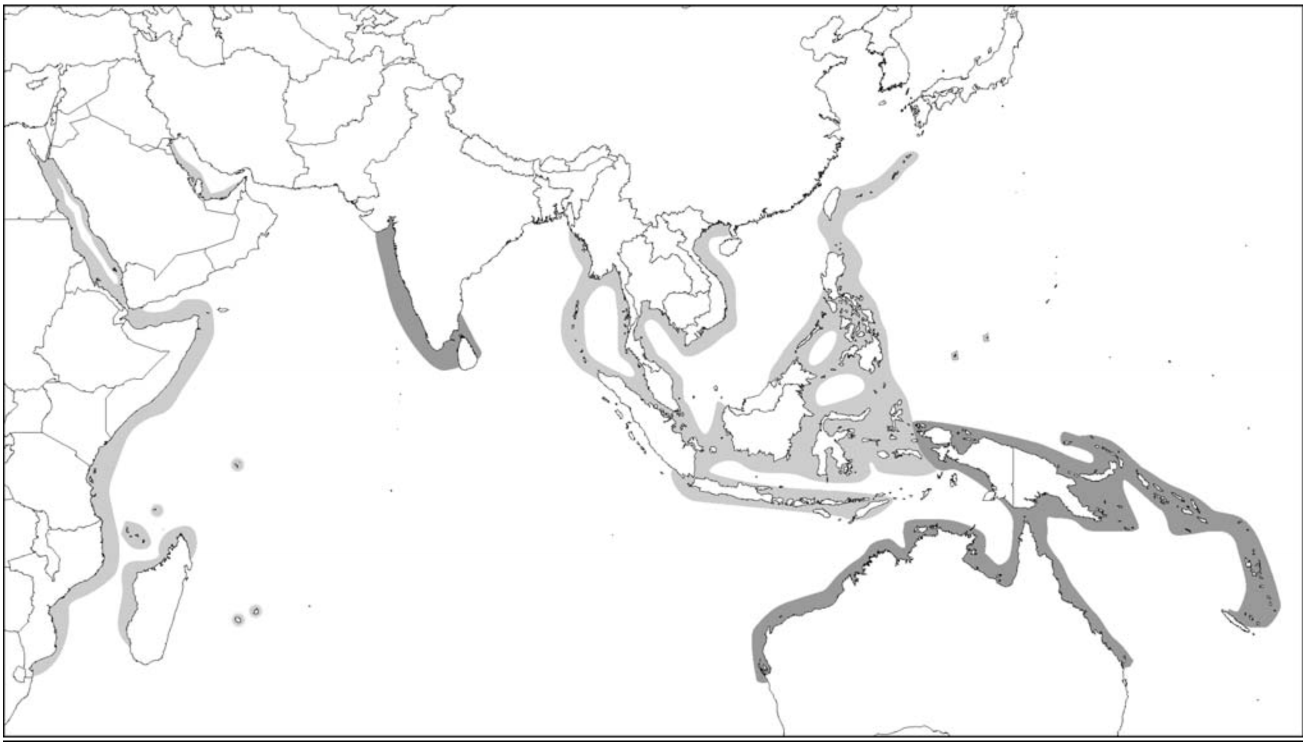

Table 1: Summary of information on dugong status and management within its range.

COUNTRIES	*Type of information available on dugong distribution and abundance*					**Management Actions**		
		Qualitative surveys		**Quantitative surveys**			**Marine Parks**	
	Anecdotal	**Some Areas**	**Entire Coast**	**Some Areas**	**Entire Coast**	**Legislation**	**Generic but should protect dugongs**	**Specifically designed for dugongs**
EAST AFRICA								
Somalia	✓	✓						
Kenya	✓	✓				✓	✓	
Tanzania	✓						✓	
Mozambique	✓	✓		✓				
Madagascar	✓							
Comoros	✓							
Mayotte	✓							
Seychelles	✓						✓	
Mauritius	extinct?							
RED SEA								
Egypt	✓							
Sudan	✓						✓	
Eritrea	✓						✓	
Yemen	✓							
Djibouti	✓							
Saudi Arabia	✓		✓		✓			
THE ARABIAN GULF								
United Arab Emirates	✓		✓		✓	✓		

Qatar	✓		✓		✓			planned
Bahrain	✓		✓		✓	✓		
Saudi Arabia	✓		✓		✓			
INDIA AND SRI LANKA								
Mainland India	✓	✓				✓	✓	
Andaman Islands	✓					✓		
Nicobar Islands	✓					✓		
Sri Lanka	✓	✓						
EAST AND SOUTH EAST ASIA								
Japan	✓	✓	✓	✓		✓		
Taiwan (China)	✓						✓	
China	✓	✓				✓	✓	✓
Philippines	✓	✓				✓	✓	in progress
Thailand	✓		✓ [1]			✓	✓	✓
Cambodia	✓							
Vietnam	✓						✓	
Peninsular Malaysia	✓	✓				✓	✓	
Singapore	✓	✓						
East Malaysia	✓	✓				✓	planned	
Brunei	✓							
Indonesia	✓	✓				✓	✓	
PACIFIC ISLANDS								
Palau	✓	✓				✓		
Papua New Guinea	✓	✓				✓		✓
Solomon Islands	✓							
New Caledonia	✓					✓		
Vanuatu	✓	✓				✓		
AUSTRALIA								

Western Australia	✔	✔		✔		✔	✔	
Northern Territory and Queensland coast of the Gulf of Carpentaria	✔		✔	✔		✔	✔	
Torres Strait to Northern Great Barrier Reef	✔	✔		✔		✔	✔	✔
Urban coast of Queensland	✔			✔	✔	✔	✔	✔

[1] Entire coast of the Andaman Sea

Table 2 – Summary of information regarding current threats to dugongs.
A lack of information for a country or territory does not confirm that threats do not exist, rather that data are unavailable.
Historical accounts of threats to dugongs that are currently questionable are denoted: ?

COUNTRY	FISHING			HABITAT LOSS/DEGRADATION			HUNTING			BOAT IMPACTS		
	Gill and Mesh Nets	**Explosives**	**Other**	**Coastal Develop-ment**	**Fishing**	**Other**	**Meat**	**Medicine**	**Other**	**Deaths**	**Eco-tourism**	**Other**
EAST AFRICA												
Somalia	✔		✔	✔	✔ [1]	✔ [2]						
Kenya	✔	✔	✔	✔	trawl	✔ [3]	✔ ?	✔ ?	✔ ?	✔		injuries
Tanzania	✔	✔	✔	✔	trawl	mining, logging, urban pollution and agricultur-al runoff	✔ ?					
Mozambique	✔	✔	✔	✔	trawl							
Madagascar	✔	✔	✔	✔	trawl							
Comoros	✔											
Mayotte	✔											
Seychelles	✔											
Mauritius	✔	✔	✔									
RED SEA												
Egypt	✔		✔	✔	trawl	oil/ sewage pollution, mining, ballast						injuries, habitat displace-ment
Sudan	✔			✔	trawl		✔	✔				
Eritrea	?		✔	✔	✔		✔	✔				
Yemen	✔		✔	✔	trawl		✔ ?	✔ ?	armour?			
Djibouti	?			✔	✔		✔	✔	armour			

Saudi Arabia	✓		✓	✓	trawl	water, agricultur-al runoff	✓ ?	✓ ?	✓ [4]			
ARABIAN GULF												
United Arab Emirates	✓			✓	✓	oil pollution, dredging, ballast water, land reclamat-ion	✓ ?	✓ ?	✓ [5]			
Qatar	✓			✓	✓		✓	✓	leather, oil			
Bahrain	✓			✓	✓		✓	4				
Saudi Arabia	✓		✓	✓	trawl		✓ ?	✓ ?				
INDIA AND SRI LANKA												
Mainland India	✓	✓	✓	✓	trawl	agricultur-al runoff, dredging, seagrass maricult-ure, hurricanes	✓	✓	✓ [5]			
Andaman Islands	✓	✓	✓		trawl		✓ ?	✓ ?				
Nicobar Islands	✓	✓	✓		trawl		✓ ?	✓ ?				
Sri Lanka	✓	✓	✓	✓	trawl		✓ ?	✓ ?				
EAST AND SOUTHEAST ASIA												
Japan	✓		trap nets	✓		✓ [6]	✓ ?		crafts			
Taiwan (China)	✓		trap nets	✓		✓ [7]						
China	✓	✓	trawl	✓	✓	✓ [8]	✓ ?	✓ ?		✓		✓ [9]

Philippines	✔	✔	✔ [10]	✔	✔	✔ [11]	✔	✔	ornament		✔	
Thailand	✔	✔ ?	✔ [12]	✔	✔ [13]	✔ [14]	✔ ?	✔ ?	aphrodis-iac	✔		
Cambodia	✔	✔	trawl		push nets	✔ [15]	✔	✔	aphrodis-iac			
Vietnam	✔	✔	trawl		✔	✔ [16]	✔ ?	✔ ?				
Peninsular Malaysia	✔		traps	✔	✔	agricultur-al runoff, urban pollution	✔ ?	✔ ?	leather, aphrodis-iac	✔		injuries
Singapore	✔		traps	✔	✔	urban pollution		✔ ?		✔		✔ [17]
East Malaysia	✔	✔	traps, trawl	✔	beach seine	✔ [18]	✔ ?	✔	aphrodis-iac	✔		injures
Brunei	✔			✔			✔ ?					
Indonesia	✔	✔	✔ [19]	✔		✔ [20]	✔	✔	✔ [21]	✔		injuries
PACIFIC ISLANDS												
Palau		✔		✔		agricultur-al runoff	✔		jewellery			?
Papua New Guinea	✔					agricultur-al runoff, mining	✔		crafts, drums			
Solomon Islands	?					agricultur-al runoff	✔					
New Caledonia	✔			✔		✔ [22]	✔			✔		injuries
Vanuatu	✔			✔		runoff	✔		oil, crafts		✔	?

AUSTRALIA												
Western Australia	✔			✔	✔	✔ [23]	✔	✔ ?	✔ [24]	✔	✔	
Northern Territory and Queensland coast of the Gulf of Carpentaria	✔			✔	✔	cyclones, mining, dredging	✔	✔ ?				habitat displace-ment
Torres Strait to Northern Great Barrier Reef	✔			✔	✔	land use, mining	✔	✔ ?	jewellery			
Urban coast of Queensland	✔			✔	✔	✔ [25]	✔	✔ ?	jewellery	✔	✔	

[1] Trawling and traps
[2] Agricultural runoff
[3] Pollution, sedimentation
[4] Oil, leather, armour
[5] Oil, aphrodisiac
[6] Urban pollution
[7] Urban/thermal pollution, mining, agricultural runoff
[8] Aquaculture, mining, pollution, siltation
[9] Habitat displacement
[10] Trawling, baynets and fish corrals
[11] Aquaculture, logging, dredging, urban/oil pollution, agricultural runoff, submarine tailing placement
[12] Baynets, trawl, beach seines
[13] Push nets, trawl
[14] Mining, water pollution, sedimentation, boat propellers
[15] Agricultural runoff
[16] Sediment runoff, waste discharge, dam construction, typhoons
[17] Habitat displacement, injuries
[18] Urban pollution, agricultural runoff, salinity
[19] Trap nets, push nets, cyanide, fish weirs
[20] Logging, agricultural runoff, urban pollution, mining, dredging
[21] Aphrodisiac, ornaments, artefacts, oils/perfumes
[22] Agricultural runoff, sewage, mining
[23] Dredging, propeller damage to seagrass, aquaculture, cyclones
[24] Tusks (by the west Kimberley people)
[25] Agricultural runoff, urban pollution, cyclones

Table 3: Summary of information on dugong status and an evaluation of prospects throughout its range.

COUNTRIES	**Evidence of decline**[1]	*Conclusion re: status*	*Basis for conclusion*
EAST AFRICA		High risk of extinction	• Populations apparently small and fragmented • Considerable pressure from gill-netting, shark meshing and habitat destruction • Few effective conservation initiatives
Somalia			
Kenya	✓		
Tanzania	✓		
Mozambique	✓		
Madagascar	✓		
Comoros	✓		
Mayotte	✓		
Seychelles	✓		
Mauritius	✓ ? extinct		
RED SEA		Reasonable prospects for survival	• Likely that region supports significant numbers of dugongs • Human population density and coastal impacts low on Saudi coast
Egypt			
Sudan			
Eritrea			
Yemen			
Djibouti			
Saudi Arabia			
ARABIAN GULF		Uncertain prospects for survival	• Second largest dugong population in the world (7307± s.e. 1302; Preen 1989). • Habitat threatened by coastal development and oil spill • Few effective conservation initiatives
United Arab Emirates			
Qatar			
Bahrain			

Saudi Arabia			
INDIA AND SRI LANKA		High risk of extinction	• Populations apparently small, fragmented and isolated • Pressure from gill netting, dynamite fishing, habitat destruction and hunting likely to increase • Few effective conservation initiatives
Mainland India	✔		
Andaman Islands	✔		
Nicobar Islands	✔		
Sri Lanka	✔		
EAST AND SOUTH EAST ASIA		Uncertain; likely extinction in Japan	• Populations apparently small and fragmented. but cover vast areas with potential for recruitment from other areas • Japanese population extremely small and isolated and subject to habitat loss and fishing impacts • Pressure from gill-netting, dynamite fishing, habitat destruction, boat impacts and hunting likely to increase • Few effective conservation initiatives
Japan	4		
Taiwan (China)	*extinct or never there*		
China	✔		
Philippines	✔		
Thailand	✔		
Cambodia	✔		
Vietnam			
Peninsular Malaysia			
Singapore			
East Malaysia	✔		
Brunei			
Indonesia	✔		
PACIFIC ISLANDS		Uncertain; likely extinction in Palau	• Populations apparently small and fragmented. potential for recruitment from other areas uncertain • Palau population extremely small and isolated • Pressure from gill-netting, dynamite fishing, habitat destruction and hunting likely to increase • Few conservation initiatives
Palau	✔		
Papua New Guinea	✔		
Solomon Islands			
New Caledonia	✔		
Vanuatu			

AUSTRALIA		Secure except for urban coast of Queensland	• Region supports large numbers of dugongs (estimated population 85,000+; Marsh et al. 1999) • Human population density and coastal impacts low except on urban coast of Queensland • Population changes confounded by large-scale movements • Active conservation initiatives, including dugong-specific actions especially along east coast of Queensland.
Western Australia			
Northern Territory and Queensland coast of Gulf of Carpentaria			
Torres Strait and Northern Great Barrier Reef			
Urban coast of Queensland	✔		

[1]Evidence of decline anecdotal except on urban coast of Queensland, Australia.

References

Anderson, P. K. 1981. The behaviour of the dugong (*Dugong dugon*) in relation to conservation and management. *Bulletin of Marine Science* **31**, 640-647.

Anderson, P. K. 1982a. Studies of dugongs at Shark Bay, Western Australia II. Surface and Subsurface observations. *Australian Wildlife Research* **9**, 85-100.

Anderson, P. K. 1982b. Studies of dugongs at Shark Bay, Western Australia I. Analysis of population size, composition, dispersion and habitat use on the basis of aerial survey. Australian *Wildlife Research* **9**, 69-84.

Anderson, P. K. 1986. Dugongs of Shark Bay, Australia – seasonal migration, water temperature and Forage. *National Geographic Research* **2**, 473-490.

Anderson, P. K. 1989. Deliberate foraging on macro-invertebrates by dugongs. *National Geographic Research* **5**, 4-6.

Anderson, P. K. 1998. Shark Bay dugongs (*Dugong dugon*) in summer. II: Foragers in a *Halodule*- dominated community. *Mammalia* **62**, 409-425.

Anderson, P. K., and Barclay, R. M. 1995. Acoustic signals of solitary dugongs: physical characteristics and behavioural correlates. *Journal of Mammalogy* **76**, 1226-1237.

Anonymous. 1992. Review of the operation and maintenance of shark meshing equipment in Queensland waters. Report of the Committee of Enquiry. Queensland Department of Primary Industries, Brisbane, Australia.

Anonymous. 1996. World Resources 1996-1997. A guide to the Global Environment. A report by World Resource Institute, UNEP, UNDP and the World Bank. Oxford University Press, Melbourne, Australia.

Anonymous. 1997. Shoalwater Bay (Dugong) Plan of Management. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Aragones, L. 1996. Dugongs and green turtles: grazers in the tropical seagrass ecosystem. PhD Thesis. James Cook University of North Queensland, Townsville, Australia.

Aragones, L., and Marsh, H. 2000. Impacts of dugong grazing and turtle cropping on tropical seagrass communities. *Pacific Conservation Biology* **5**, 277-288.

Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology* **63**, 215-244.

Cockcroft, V. G., and Young, D. D. 1998. An investigation of the status of coastal marine resources along the west coast of Madagascar. Unpublished report. World Wide Fund for Nature (WWF), Gland, Switzerland.

Cockcroft, V. G., Salm, R. V., and Dutton, T. P. 1994. The status of dugongs in the western Indian Ocean. First International Manatee and Dugong Research Conference. March 11-13. Gainesville, Florida.

Day, J. C., Fernandes, L., Lewis, A., De'ath, G., Slegers, S. B., Barnett, Kerrigan, B., Breen, B., Innes, D., Oliver, J., Ward, T., and Lowe, D. In press. The Representative Areas Program – protecting the biodiversity of the Great Barrier Reef World Heritage Area. Proceedings of the 9th International Coral Reef Symposium, Bali, Indonesia 23-27 October 2000.

DeMaster, D. P., Fowler, C. W., Perry, S. L., and Richlen, M. F. 2001. Predation and competition: the impact of fisheries on marine mammal populations over the next one hundred years. Journal of Mammalogy 82, 641-651.

Denton, G. R., Marsh, H., Heinsohn, G. E., and Burdon-Jones, C. 1980. The unusual heavy metal status of the dugong. *Marine Biology* **57**, 201-219.

Fonseca, M. S. 1987. The management of seagrass systems. *Tropical Coastal Area Management*
2, 5-7.

Gerstein, E. R. 1994. The manatee mind: discrimination training for sensory perception testing of West Indian Manatees (*Trichechus manatus*). *Marine Mammals: Public Display and Research* **1**, 10-21.

Gerstein, E. R. 1995. Underwater audiogram of the West Indian Manatee (*Trichechus manatus latirostris*). Masters Thesis, Florida Atlantic University, Boca Raton, Florida.

Gerstein, E. R., Gerstein, L., Forsythe, S. E., and Blue, J. E. 1999. The underwater audiogram of the West Indian manatee (*Trichechus manatus*). *Journal of Acoustical Society America* 1**05**, 3575-83.

Gribble, N. A., McPherson, G., and Lane, B. 1998. Effect of the Queensland Shark Control Program on non-target species: whale, dugong, turtle and dolphin: a review. *Marine and Freshwater Research* **49**, 645-651.

Hartman, D. S. 1979. Ecology and behaviour of the manatee (*Trichechus manatus*) in Florida. Special Publication No. **5,** American Society of Mammalogists.

Haynes, D. 2001. Pesticides and heavy metal concentrations: impacts on Great Barrier Reef sediments, seagrass and dugong (*Dugong dugon*). PhD thesis. Marine Botany Department, University of Queensland, Brisbane, Australia.

Haynes, D., Slater, J., Devlin, M., and Makey, L. 1998. Great Barrier Reef water quality monitoring and dugong protection areas. *Reef Research* **8**, 10-15.

Haynes, D., Müller, J., and McLachlan, M. S. 1999. Polychlorinated dibenzo-p-dioxins and dibenzofurans in Great Barrier Reef (Australia) dugongs (*Dugong dugon*). *Chemosphere* **38**, 255-262.

Heinsohn, G. E., and Spain, A. V. 1974. Effects of a tropical cyclone on littoral and sub-littoral biotic communities and on a population of dugongs (*Dugong dugon* (Muller)) *Biological Conservaiton* **6**, 143-152.

Heinsohn, G. E., Marsh, H., and Anderson, P. K. 1979. Australian dugong. *Oceans* **12**, 48-52.

Hilton-Taylor, C. (compiler) 2000. 2000 IUCN Red List of Threatened Species. IUCN, Gland, Switzerland. http://www.redlist.org/

Hughes, G. R., and Oxley-Oxland, R. 1971. A survey of dugong (*Dugong dugon*) in and around Antonio Enes, Northern Mozambique. *Biological Conservation* **3**, 299-301.

Husar, S. 1975. A review of the literature of the dugong (Dugong dugon). US Department of International Fish and Wildlife Service Wildlife Research Report **4**, 1-30.

Husar, S. 1978. *Dugong dugon*. *Mammalian Species* **88**, 1-7.

Iongh, H. H. De. 1996a Plant-herbivore interactions between seagrasses and dugongs in a tropical small island ecosystem. Phd. Thesis, Catholic ?University of Nijmegen, The Netheralnds; 205pp.

Iongh, H. H. De. 1996b. Current status of dugongs in Aru, Eastern Indonesia. In ‘The Aru Archipelago: plants, animals, people and conservation’. (Ed Nooteboom) pp. 75-86. Mededelingen no. 30. (Nederlandse Commissie voor Internationale Natuurbescherming)

Iongh, H. H. De., Langeveld, P., and Van Der Wal, M. 1998. Movement and home ranges of dugongs around the Lease Islands, East Indonesia. *Marine Ecology* **19**, 179-193.

Johnston, P. A., Stringer, R. L., and Santillo, D. 1996. Cetaceans and environmental pollution: the global concerns. In ‘The Conservation of Whales and Dolphins’.

(Eds M.P. Simmonds and J.D. Hutchinson.) pp. 219-61. (John Wiley and Sons: New York.)

Jones, S. L. 1967. The dugong *Dugong dugon* (Muller): its present status in the seas around India with observations on its behaviour in captivity. *International Biological Yearbook* **7** ,215-220.

Kasuya, T., Ogawa, H., Yokochi, H., Hosokawa, T., Shirakihara, M., and Higashi, M. 2000. Japanese dugongs, their current status and conservation measures required. Report of 1999 dugong survey. In '9th Report of Pro-Natura Fund'. Japanese Association Protection of Nature, Tokyo. [In Japanese with English summary.]

Kenyon, R., and Poiner, I. 1987. Seagrass and cyclones in the western Gulf of Carpentaria. CSIRO Marine Laboratory Information Sheet, February, 1987.

Kuiken, T., Bennett, P. M., Allchin, C. R., Kirkwood, J. K., Baker, J. R., Lockyer, C. H., Walton, M. J., and Sheldrick, M. C. 1994. PCBs, cause of death and body condition in harbor porpoises (*Phocoena phocoena*) from British waters. *Aquatic Toxicology* **28**, 13-28.

Kwan, D. 2002. Towards a sustainable fishery for dugongs in Torres Strait: a contribution of empirical data and process. PhD thesis James Cook University.

Lanyon, J. M. 1991. The nutritional ecology of the dugong (*Dugong dugon*) in tropical north Queensland. PhD Thesis, Monash University.

Lee Long, W. J., and Coles, R.G. 1997. Status of seagrasses in the Great Barrier Reef region. In 'State of the Great Barrier Reef World Heritage Area Workshop: proceedings of a technical workshop held in Townsville, Queensland, Australia, 27-29 November 1995. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Lee Long, W. J., Mellors, J. E., and Coles, R.G. 1993. Seagrasses between Cape York and Hervey Bay, Queensland, Australia. *Australian Journal of Marine and Freshwater Research* **44**, 19-31.

Lee Long, W. J., Coles, R. G., and McKenzie, L. J. 1996. Deepwater seagrass in Northern Australia – how deep and how meaningful? In 'Seagrass Biology: Proceedings of an International Workshop'. (Eds J. Kuo, R. C. Phillips, D. I. Walker and H. Kirkman). pp 41-50. (University of Western Australia. Perth)

Longstaff, B. J., Loneragan, N. R., O'Donohue, M. J., and Dennison, W. C. 1999. Effects of light deprivation on the survival and recovery of the seagrass

Halophila ovalis (R.Br) Hook. *Journal of Experimental Marine Biology and Ecology* **234**, 1-27.

Marsh, H. 1980. Age determination of the dugong (*Dugong dugon*) (Müller) in northern Australia and its biological implications. Report of the International Whaling Commission Special Issue **3**, 181-201.

Marsh, H. 1989. Mass stranding of dugongs by a tropical cyclone in northern Australia. Marine Mammal Science **5:** 78-84.

Marsh, H. 1995a. The life history, pattern of breeding, and population dynamics of the dugong. In ‘Proceedings of a workshop on manatee population biology’. (Ed. T.J. O’Shea.) pp. 75-83. U.S. Fish and Wildlife Service Technical Report.

Marsh, H. 1995b. Limits of detectable change. In ‘Conservation through sustainable use of wildlife’. (Eds G. Grigg, P.Hale and D. Lunney.) pp. 120-130. (Surrey Beatty and Sons: Sydney.)

Marsh, H. 1999. Reproduction in Sirenians. In ‘Reproduction in marine mammals’. (I.L. Boyd, C. Lockyer and H.D. Marsh) In ‘Marine Mammals’. (Eds J.E. Reynolds and J.R. Twiss.) pp. 243-256. (Smithsonian Institute Press: Washington.)

Marsh, H. 2000. Evaluating management initiatives aimed at reducing the mortality of dugongs in gill and mesh nets in the Great Barrier Reef World Heritage Area. *Marine Mammal Science* **16**, 684-694.

Marsh, H. and Lawler, I. R. 2002. Dugong distribution and abundance in the northern Great Barrier Reef Marine Park -November 2000. *GBRMPA Research Publication* **77**. GBRMPA Townsville. http://www.gbrmpa.gov.au.

Marsh, H. and Lefbvre, L. W. 1994. Sirenian status and conservation efforts. *Aquatic Mammals* **20**:155-70.

Marsh, H., and Rathbun, G. B. 1990. Development and application of conventional and satellite radio-tracking techniques for studying dugong movements and habitat usage. *Australian Wildlife Research* **17**, 83-100.

Marsh, H., and Saalfeld, W. K. 1989. The distribution and abundance of dugongs in the northern Great Barrier Reef Marine Park. *Australian Wildlife Research* **16**, 429-440.

Marsh, H., and Saalfeld, W. K. 1991. The status of the dugong in Torres Strait. In ‘Sustainable development of traditional inhabitants of the Torres Strait

Region. (Eds D. Lawrence and T. Cansfield-Smith) pp. 187-194. Great Barrier Reef Marine Park Authority Workshop Series 10.

Marsh, H., Channells, P. W., Heinsohn, G. E. and Morissey, J. 1982. Analysis of stomach contents of dugongs from Queensland. *Australian Wildlife Research* **9**, 55-67.

Marsh, H., Heinsohn, G. E., and Channells, P. W. 1984. Changes in the ovaries and uterus of the dugong, *Dugong dugon* (Sirenia: Dugongidae), with age and reproductive activity. *Australian Journal of Zoology* **32**, 743-766.

Marsh, H., Saalfeld, W. K., and Preen, A. R. 1990. The distribution and abundance of dugongs in southern Queensland waters: implications for management. Report to Queensland Department of Primary Industries.

Marsh, H., Prince, R. I. T., Saalfeld, W. K., and Shepherd, R. 1994. The distribution and abundance of dugongs in Shark Bay. *Wildlife Research* **21**, 149-61.

Marsh, H., Harris, A. H. N., Lawler, I. R. 1997a. . The sustainability of the Indigenous dugong fishery in Torres Strait, Australia/Papua New Guinea. *Conservation Biology* **11**: 1375:1386.

Marsh, H., Corkeron, P., Morissette, N., and Preen, A. R. 1997b. An assessment of the sustainability of the Indigenous dugong fishery in Torres Strait. Unpublished Report prepared for Australian Fisheries Management Authority.

Marsh, H., Eros, C, Corkeron, P., and Breen, B. 1999. A conservation strategy for Dugongs: implications of Australian Research. *Marine and Freshwater Research* **50**, 979-90.

Marsh, H., Penrose, H., Eros, C., and Hugues, J. 2002. The Dugong (Dugong dugon) Status Reports and Action Plans for Countries and Territories in its Range. Final Report, United Nations Environment Programme, Nairobi, Kenya.

Marsh, H., De’ath, G., Gribble, N., and Lane, B. 2001. Shark control records hindcast serious decline in dugong numbers off the urban coast of Queensland. Unpublished report to the Department of Environment, Australia.

McCauley, R. D. 1994. Environmental Implications of offshore oil and gas development in Australia-Seismic surveys. In ‘Environmental Implications of offshore oil and gas development in Australia. (Ed. Anon.) pp. 19-121. (Australian Petroleum Exploration Association Ltd.)

McLachlan, M. S., Haynes, D., and Müller, J. F. 2001. PCDDs in the water/sediment-seagrass-dugong (*Dugong dugon*) food chain on the Great Barrier Reef (Australia). *Environmental Pollution* **113**, 129-134.

Miyazaki, N., Itano, K., Fukushima, M., Kawai, S., and Honda, K. 1979. Metals and organochlorine compounds in the muscle of dugong from Sulawesi Island. Scientific Reports of the Whales Research Institute **31**, 125-128.

Nishiwaki, M., and Marsh, H. 1985. The dugong. In 'Handbook of marine mammals Volume 3. (Eds S.H. Ridgway and R.J. Harrison.) pp. 1-31. (Academic Press: London).

Paterson, R. 1990. Effects of long-term anti-shark measures on target and non-target species in Queensland, Australia. *Biological Conservation* **52**, 147-159.

Perrin, W. F., Dolar, M. L. L., and Alava, M. N. R. 1996. Report of the workshop on the biology and conservation of small cetaceans and dugongs of Southeast Asia, Dumaguete, 27-30 June 1995. United Nations Environment Programme, Bangkok.

Poiner, I. R., and Peterken, C. 1996. Seagrasses. In 'The State of the Marine Environment Report for Australia'. (Eds L. P. Zann and P. Kailola.) The State of the Marine Environment Report for Australia. Technical Annex: 1. (Great Barrier Reef Marine Park Authority, Townsville, Australia)

Preen, A. R. 1989. Technical Report, Dugongs, Volume 1: The status and conservation of dugongs in the Arabian Region. MEPA Coastal and Marine Management Series, Saudi Arabia.

Preen, A. R. 1992. Interactions between dugongs and seagrasses in a subtropical environment. PhD thesis. James Cook University of North Queensland, Townsville, Australia.

Preen, A. R. 1995a Diet of dugongs; are they omnivores? *Journal of Mammalogy* **76:** 163-71.

Preen, A. R. 1995b. Impacts of dugong foraging on seagrass habitats: observational and experimental evidence for cultivation grazing. *Marine Ecology Progress Series* **124**: 201-13.

Preen, A. R. 1995c. Movements and home ranges of dugongs in the south-west Gulf of Carpentaria, as determined by satellite telemetry. Unpublished report to the Australian Heritage Commission, the Conservation Commission of the Northern Territory and McArthur River Mine.

Preen, A. R. 1998. Marine protected areas and dugong conservation along Australia's Indian Ocean coast. *Environmental Management* **22**, 173-181.

Preen, A. R. 1999. Dugongs in the Shoalwater Bay area. Draft Report for the Great Barrier Reef Marine Park Authority, Townsville, Australia.

Preen, A. R. 2001. Dugongs, boats, dolphins and turtles in the Townsville-Cardwell region and recommendations for a boat traffic management plan for the Hinchinbrook Dugong Protection Area. Great Barrier Reef Marine Park Authority Research Publication No. **67**., Townsville, Australia.

Preen, A. R., and Marsh, H. 1995. Response of dugongs to large-scale loss of seagrass from Hervey Bay, Queensland, Australia. *Wildlife Research* **22**, 507-519.

Preen, A. R., Lee Long, W. R., and Coles, R. G. 1995. Flood and cyclone related loss, and partial recovery, of more than 1000km^2 of seagrass in Hervey Bay, Queensland, Australia. *Aquatic Botany* **52**, 3-17.

Reynolds, J. E., and Odell, D. K. 1991. Manatees and Dugongs. Facts on File Inc., New York.

Richardson, W. J., and Malme, C. I. 1993. Man-made noise and behavioural responses. In ' The Bowhead Whale. Special Publication **2**'. (Eds J.J. Burns, J.J. Montague and C.J.Cowles.) pp. 631-700.(Society for Marine Mammalogy: Lawrence, Kansas.)

Richardson, W. J., Green (Jr) C. R., Malme, C. I., and Thomson, D. H. 1995. Marine mammals and noise. (Academic Press: Sydney.)

Shepherd, S., McComb, A. J., Bulthuis, D. A., Neverauskas, V., Steffensen, D. A., and West, R. 1989. Decline of seagrass. In 'Biology of seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region.' (Eds A.W.D. Larkum, A.J. McComb and S.Shepherd). pp. 346-393. (Elsevier: Amsterdam.)

Silas, E. G., and Bastion-Fernando, A. 1985. The dugong in India- is it going the way of the Dodo? Proceedings of the Symposium on Endangered Marine Animals and Marine Parks, 1985 Volume1. Cochin, India.

Spain, A. V., and Heinsohn, G. E. 1973. Cyclone associated feeding changes in the dugong (Mammalia: Sirenia). *Mammalia* **37**, 678-80.

Stejneger, L. 1887. How the great northern sea cow (*Rytina*) became exterminated. *American Naturalist*(21): 1047-1054.

Suprawinid, C. 1996. Recovery of the seagrass *Halophila ovalis* after grazing by Dugong. In 'Seagrass Biology, Proceedings of an International Workshop, Rottnest Island, Western Australia, 25-29 January 1996'. (Eds J .Kuo, R.C. Phillips, D.I .Walker and H. Kirkman. . pp. 315-18. Faculty of Science, University of Western Australia, Nedlands, Western Australia.

Tikel, D. 1998. Using a genetic approach to optimise dugong (*Dugong dugon*) conservation and management. PhD thesis. James Cook University, Townsville, Australia.

Trippel, E. A., Strong, M. B., Terhune, J. M., and Conway, J. D. 1999. Mitigation of harbor porpoise (*Phoceana phocoena*) by-catch in the gill net fishery in the lower Bay of Fundy. Canadian *Journal of Fisheries and Aquatic Science* **56**, 113-123.

Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of Cetaceans and Pinnipeds. *Marine Mammal Science* **14**, 1-37.

Whiting, S. D. 1999. Use of the remote Sahul Banks, Northwestern Australia, by dugongs, including breeding females. *Marine Mammal Science* **15**, 609-615.

Wright, S. D., Ackerman, B. B., Bonde, R. K., and Beck, C. A. 1995. Analysis of watercraft-related mortality of manatees in Florida, 1979-1991. In 'Population biology of the Florida Manatee'. (Eds T. J. O'Shea, B. B. Ackerman and H. F. Percival) US Department of the Interior. National Biological Service, Information and Technology Report No. 1.