Extinction Risk Assessment of the World's Seagrass Species

ARTICLE *in* BIOLOGICAL CONSERVATION · MAY 2011

Impact Factor: 3.76 · DOI: 10.1016/j.biocon.2011.04.010

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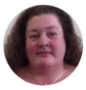

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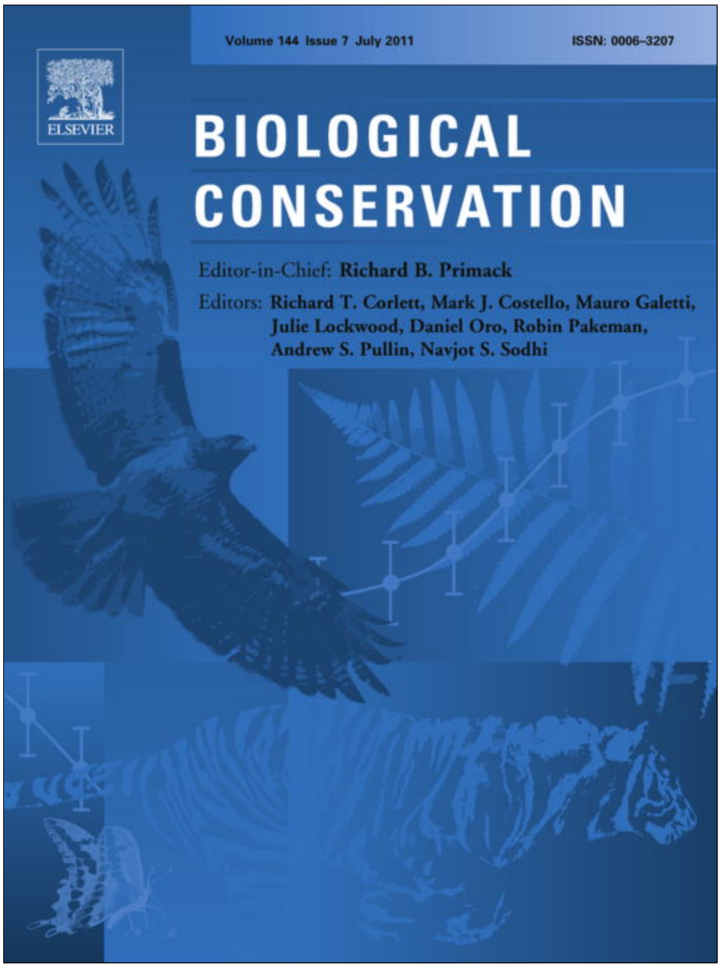
Volume 144 Issue 7 July 2011
ISSN: 0006-3207
ELSEVIER
BIOLOGICAL CONSERVATION
Editor-in-Chief: Richard B. Primack
Editors: Richard T. Corlett, Mark J. Costello, Mauro Galetti, Julie Lockwood, Daniel Oro, Robin Pakeman, Andrew S. Pullin, Navjot S. Sodhi

Biological Conservation 144 (2011) 1961–1971

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

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A R T I C L E I N F O

Article history:
Received 20 December 2010
Received in revised form 16 March 2011
Accepted 4 April 2011
Available online 5 May 2011

Keywords:
Seagrass
Red List
Extinction

A B S T R A C T

Seagrasses, a functional group of marine flowering plants rooted in the world's coastal oceans, support marine food webs and provide essential habitat for many coastal species, playing a critical role in the equilibrium of coastal ecosystems and human livelihoods. For the first time, the probability of extinction is determined for the world's seagrass species under the Categories and Criteria of the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species. Several studies have indicated that seagrass habitat is declining worldwide. Our focus is to determine the risk of extinction for individual seagrass species, a 4-year process involving seagrass experts internationally, compilation of data on species' status, populations, and distribution, and review of the biology and ecology of each of the world's seagrass species. Ten seagrass species are at elevated risk of extinction (14% of all seagrass

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0006-3207/$ - see front matter
doi:10.1016/j.biocon.2011.04.010

Threatened
Endangered
Biodiversity

species), with three species qualifying as Endangered. Seagrass species loss and degradation of seagrass biodiversity will have serious repercussions for marine biodiversity and the human populations that depend upon the resources and ecosystem services that seagrasses provide.

1. Introduction

Seagrasses represent one of the richest and most important coastal habitats in the ocean, supporting a range of keystone and ecologically important marine species from all trophic levels (Orth et al., 2006). They are underwater flowering plants (in the class Monocotyledoneae) that form vast meadows, flowering and seeding under water, having evolved from terrestrial origins and re-entered the sea millions of years ago. Seagrasses alone create an important marine habitat, but are also a component of more complex ecosystems within marine coastal zones, contributing to the health of coral reefs and mangroves, salt marshes and oyster reefs (Dorenbosch et al., 2004; Duke et al., 2007; Heck et al., 2008; Unsworth et al., 2008). Seagrasses have high primary productivity and are a basis of many marine food webs through direct herbivory and the detrital cycle, both within the seagrass beds and as wrack which washes ashore (Hemminga and Duarte, 2000); they provide nutrients (N and P) and organic carbon to other parts of the oceans, including the deep sea, and contribute significantly to carbon sequestration (Suchanek et al., 1985; Duarte et al., 2005). The value of ecosystem services of seagrasses has been estimated at US$34,000 per hectare per year (Costanza et al., 1997, here recalculated to 2010 dollars), greater than many terrestrial and marine habitats. Seagrass habitats also support artisanal fisheries and the livelihoods of millions of people in coastal communities, largely in tropical regions (de la Torre-Castro and Ronnback, 2004; Björk et al., 2008; Unsworth and Cullen, 2010). Seagrass is the primary food of dugong, manatee, and some sea turtles, all of which are threatened themselves (Green and Short, 2003; IUCN, 2010).

The additional ecosystem services that seagrasses provide are many (Orth et al., 2006; Heck et al., 2008). The structure of the leaves acts as a filter, clearing the water of suspended sediments; leaves, roots and rhizomes take up and cycle nutrients. The complex root structure of seagrass beds secures and stabilizes sediments providing essential shoreline protection and reduction of coastal erosion from extreme storm events (Koch, 2001; Björk et al., 2008). Seagrass leaves form a three-dimensional habitat creating shelter for many other marine species. The leaves serve as a surface for attachment for a wide variety of small encrusting algae and animals. These in turn provide an important food source for larger seagrass-associated animals. Seagrasses are a nursery ground for juvenile and larval stages of many commercial, recreational and subsistence fish and shellfish (Watson et al., 1993; Beck et al., 2001; Heck et al., 2003; de la Torre-Castro and Ronnback, 2004).

Synoptic studies to date have examined the distribution, status and trends of seagrass habitat, and have clearly indicated that seagrasses are declining globally (Green and Short, 2003; Orth et al., 2006; Waycott et al., 2009). A synthesis of 215 published studies showed that seagrass habitat disappeared worldwide at a rate of 110 km^2 per year between 1980 and 2006 (Waycott et al., 2009). However, the actual status of individual seagrass species themselves has received little attention. For the first time, the likelihood of extinction of the world's 72 species of seagrass has been determined under the Categories and Criteria of the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species.

2. Methods

2.1. IUCN Red List assessment process

The IUCN Red List Categories and Criteria (IUCN, 2010) serve to assess and list extinction risk at the species level (Rodrigues et al., 2006; Mace et al., 2008) using pre-established universal criteria. The IUCN Red List Categories comprise eight levels of extinction risk: Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern and Data Deficient. A species qualifies for one of the three threatened categories (Critically Endangered, Endangered, or Vulnerable) by meeting the threshold for that category in one of the established criteria. The category of Near Threatened can be assigned to species that come close to, but do not fully meet, the thresholds or conditions required for a threatened category under the IUCN criteria. The criteria are based on extinction risk theory (Mace et al., 2008), forming the real strength of the IUCN Red List, and can be applied to species across all taxa (Carpenter et al., 2008; Schipper et al., 2008; Polidoro et al., 2010). Application of the IUCN Red List Categories and Criteria is the most widely accepted method for assessing a species' probability of extinction and its conservation status on a global scale (Butchart et al., 2005; de Grammont and Cuarón, 2006; Rodrigues et al., 2006; Hoffmann et al., 2008, 2010; Campagna et al., 2011).

Data collection and IUCN Red List Assessments for seagrass species (Fig. 1) were conducted in three regional workshops: one in Dominica for Caribbean and tropical Atlantic species in 2007, a second (at the National Center for Ecological Analysis and Synthesis, NCEAS) in Santa Barbara, California (USA) for temperate species in 2007, and a third in Batangas, Philippines for Indo-Pacific species in 2008. Twenty-one leading international seagrass experts were brought together to share and synthesize species-specific data, and to collectively apply the IUCN Red List Categories and Criteria. During these Red List assessment workshops, species were evaluated individually by the group of experts present, with outside consultation and follow-up conducted when additional information was needed. Information on taxonomy, distribution, population trends, ecology, life history, past and existing threats, and conservation actions for each seagrass species was discussed, quantified and reviewed for accuracy and consensus. That said, detailed knowledge of many seagrass species worldwide is lacking; in some cases even basic distribution information is not complete (Duarte et al., 2008). Despite these substantial uncertainties, the Red Listing process was considered an important element for long-term awareness and protection of seagrasses, which would also usefully highlight information gaps. Quantitative species information, wherever available, or a consensus of expert opinion was used to determine if a species met the threshold for a threatened category under at least one IUCN Red List Criterion. For all species that were not Data Deficient, whatever their Red List status, expert workshop consensus determined which threats were impacting the species. Finally, the findings were reviewed at two seagrass science meetings: in Hvar, Croatia (2009) at the 2nd Mediterranean Seagrass Workshop and in Bamfield, Canada (2009) at the 8th International Seagrass Biology Workshop. All species data and results of Red List assessments are freely and publicly available on the IUCN Red List of Threatened Species (IUCN, 2010).

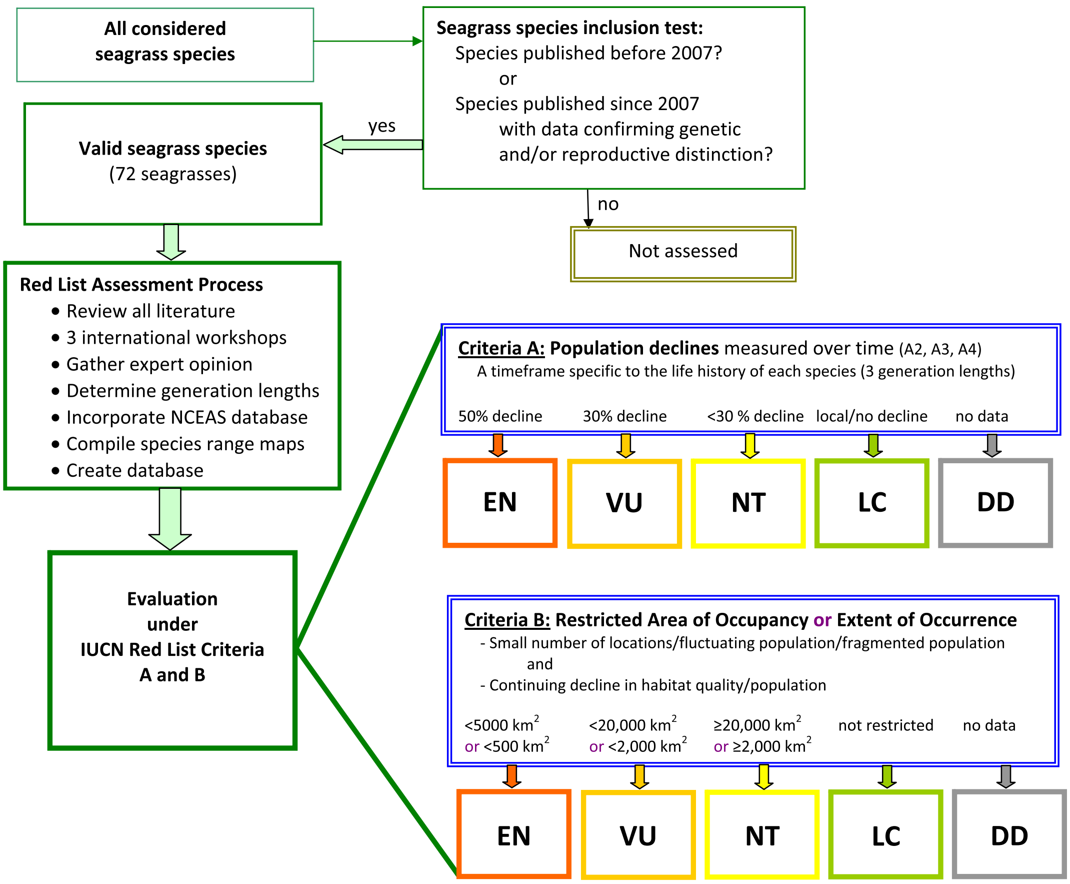

Fig. 1. Flow chart IUCN Red List Assessment for all seagrass species. Red List Categories: Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD).

2.2. Species selection

The IUCN Red List Categories and Criteria (IUCN, 2010) were applied to a total of 72 species of seagrass in six families (Fig. 1), with the selection of species based on published species records (Kuo and den Hartog, 2001; Short et al., 2007) and including the marine *Ruppia* (six species) and *Lepilaena* (two species), as well as *Zostera geojeensis* (Shin et al., 2002). Taxonomic changes since Short et al. (2007) were accepted for new species only if a complete published taxonomic description existed, documenting unique sexual reproductive characters or genetic difference (*Halophila nipponica*, *Halophila sulawesii*, and *Zostera pacifica*). Merged species since 2007 were accepted if there were published indistinguishable taxonomic features with either sexual reproductive compatibility or genetic supporting data for sameness. There is ongoing debate on the validity of several seagrass species and some species were included for review if accepted by an established taxonomic review board (Council of Heads of Australian Herbaria for the former *Heterozostera* (*Nanozostera*) group including *Zostera chilensis*, *Zostera nigricaulis*, *Zostera polychlamys*, and *Zostera tasmanica*). Four species were not assessed as they had unclear taxonomy according to our criteria: *Halophila gaudichaudii*, *Halophila major*, *Halophila mikii*, and *Halophila okinawensis*. Following the evidence summarized in Short et al. (2007) based on genetic data, *Posidonia robertsoniae* was reviewed under *Posidonia coriacea* and *Zostera (Nanozostera) capricorni*, *Zostera* (*Nanozostera*) *mucronata*, and *Zostera* (*Nanozostera*) *novazealandica* were reviewed under *Zostera muelleri*.

2.3. Application of IUCN categories and criteria

The IUCN (2010) uses several criteria to assess species risk, two of which apply to seagrasses: Criterion A, which examines population reduction over time and Criterion B, which is based on geographic range (Fig. 1). Criterion A measures extinction risk based on exceeding a threshold of population decline (30% decline for Vulnerable, 50% for Endangered, and 80% for Critically Endangered) over a timeframe of three lengths, a measure of reproductive turnover rate, in the recent past or projected near future. The database resulting from the NCEAS Global Seagrass Trajectories Working Group survey of all published literature for seagrass area change between 1879 and 2006 (Waycott et al., 2009) was used as well as expert knowledge gathered during the three regional workshops to determine seagrass species distribution change. Global monitoring of seagrass status and trends from SeagrassNet also contributed population information from July 2001 to the present (SeagrassNet, 2010).

A definition of generation length was developed specifically for seagrasses by regional workshop participants, as no definition was apparent in the literature. Generation length is defined by the IUCN Red List Guidelines (IUCN, 2010) as the average age of parents of the current cohort (i.e., newborn individuals in the population). For seagrasses, generation length was defined as the recruitment rate via sexual reproduction. Recruitment rate for each species was calculated from the time a seed or seedling is released from the parent plant through the time of creating a reproductive, mature plant – that is, the time needed for the seedling to establish, grow, and produce seeds. For example, the recruitment rate for *Posidonia sinuosa* was estimated to be approximately 20 years, based on its relatively low pollination viability and slow growth rate (Smith and Walker, 2002). By contrast, the recruitment rate of *Halophila hawaiiana* was estimated to be less than 2 years as it flowers relatively quickly, is fast growing, and has a turnover rate of approximately 15 days (Herbert, 1986). Where recruitment rate could not be determined for a given species, information from similar known species' recruitment rates was used (Hemminga and Duarte, 2000). Although seagrasses reproduce both asexually (clonally) and sexually, asexual reproduction does not create a new, genetically distinct individual; rather the same individual is colonizing a new area, increasing the size of the clone. Asexual reproduction contributes to persistence, however it does not provide greater evolutionary potential or increased resilience to environmental change, i.e., does not contribute recruitment of genetically new individuals into the population.

Criterion B measures extinction risk based on limited distribution and populations instability (IUCN, 2010). Either geographic range or area of occupancy (the area of actual occurrence) is considered, combined with habitat fragmentation, decline in area of occupancy, or decreased habitat quality (Fig. 1). To meet the threshold for the category of Vulnerable under Criterion B, the geographic range is <20,000 km^2 or area of occupancy <2000 km^2 whereas for the category Endangered these values are <5000 km^2 or <500 km^2, respectively. The geographic range size for each species was determined from mapped distributions and point data based on 10 km grids (Green and Short, 2003; IUCN, 2010). The total area of occupancy for each seagrass species was calculated from mapped species polygons cut to actual depth range. Species' geographic range sizes were then placed into one of four categories: Very small distribution (0–25,000 km^2); Small distribution (26,000–75,000 km^2); Large distribution (76,000–200,000 km^2); Very large distribution (>200,000 km^2). Species with very small distributions that were found in areas with persistent seagrass area loss and fragmentation were determined to have met the threshold for a threatened category under Criterion B. Expert workshop participants were cognizant that the relationship between habitat or occupancy area loss and species population reduction is not always linear, as loss can occur in areas of lower or higher population density (Rodrigues and Gaston, 2002).

2.4. Data analyses

Updated digital distribution maps were created for each species based on refinement of existing maps (Green and Short, 2003; UNEP-WCMC, 2010), with bioregions defined by Short et al. (2007). Each species' geographic range map was extended to 100 km from shore for cartographic purposes; range maps were then overlaid to illustrate species richness. For Data Deficient species, complete distributional limits were not available; these species were not included in species richness and population trends. The population trend for each seagrass species was calculated based on data from published studies, the Global Seagrass Trajectories Database (Waycott et al., 2009; NCEAS, 2006) and expert opinion. To examine the relationship between seagrass species traits and extinction risk, significant differences in distribution size, maximum depth, depth range and recruitment rate among seagrass species in threatened (Endangered and Vulnerable), Near Threatened and Least Concern categories were determined based on independent *t*-tests and Kruskall–Wallace Chi-square tests, or Mann Whitney Wilcoxon tests. In summary, it was hypothesized that species with smaller distributions, shallower or more narrow depth ranges, and longer recruitment rates were more likely meet the criteria for threatened categories.

3. Results and discussion

3.1. Threatened and near threatened species

Nearly one quarter (15 species, 24%) of all seagrass species that could be assigned a Red List conservation status were threatened (Endangered or Vulnerable) or Near Threatened (Table 1). Specific details and documentation by seagrass species are provided in the IUCN Red List database (IUCN, 2010). Nine species could not be assigned a conservation status due to lack of information, and were designated Data Deficient. Three species were listed as Endangered (Table 2): *Phyllospadix japonicus* (Fig. 2a) under Criteria A and B, *Z. chilensis* and *Z. geojeensis*, both under Criterion B. *P. japonicus* is an important habitat-forming species on the rocky shores of China, Korea and Japan and has lost vast areas in China as a result of seaweed aquaculture and throughout its range from land reclamation (Short per. obs.). *Z. chilensis* is known only from two locations on the coast of Chile, one of which was not found when last surveyed (Phillips et al., 1983). One of the two locations of *Z. geojeensis*, a little-known Korean species, was destroyed in coastal development (Shin et al., 2002). Seven species were listed as Vulnerable (Table 2): *Halophila baillonii, Halophila beccarii, Halophila hawaiiana, Phyllospadix iwatensis, P. sinuosa, Zostera caespitosa*, and *Zostera capensis*. All these Vulnerable species are declining (Table 1) and their declines are directly or indirectly linked to human impacts (IUCN, 2010).

Five species (7%) were listed as Near Threatened (Table 2): *Halophila engelmanni*, *H. nipponica*, *Posidonia australis*, *Zostera asiatica* and *Zostera caulescens*. Although estimated population declines for species listed as Near Threatened were not high enough to meet the threshold for a threatened category, if current declines continue these species may well qualify for a threatened category in the near future. For example, *Z. asiatica* in Japan and Korea is a deep-water species that is vulnerable to decreases in water clarity due to shoreline hardening, aquaculture, anthropogenic pollution and other human activities (IUCN, 2010).

Nine of the 10 seagrass species listed as Endangered or Vulnerable had small range sizes compared to species listed in other categories (Fig. 3). The three seagrass species listed as Endangered all have very restricted ranges, a characteristic inherently contributing to a higher extinction risk (Mace et al., 2008). Six of the seven seagrass species listed as Vulnerable also had generally smaller ranges than the less threatened species. One Vulnerable species,

Table 1
Number and percent of all seagrass species listed in each IUCN Red List Category ($n = 72$) and number and percent of population trends (increasing, decreasing, stable or unknown) in each Red List Category.

Red List category	No. of species	Increasing	Decreasing	Stable	Unknown
Endangered	3 (4%)	0	3 (100%)	0	0
Vulnerable	7 (9.5%)	0	7 (100%)	0	0
Near Threatened	5 (7%)	0	5 (100%)	0	0
Least Concern	48 (67%)	5 (10%)	6 (13%)	29 (60%)	8 (17%)
Data Deficient	9 (12.5%)	0	1 (11%)	0	8 (89%)

Table 2
Data for all 72 species of seagrass, including: Family; Species Name; IUCN Red List Category (Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC) and Data Deficient (DD)); the IUCN Red List Criteria that classified seagrass species into the Endangered and Vulnerable categories; Generation length, expressed as Recruitment Rate in years (Gen. Length); minimum depth in meters (Min. Depth); maximum depth in meters (Max. Depth); depth range in meters (Depth Range); Bioregion from Short et al., 2007 (1 = Temperate North Atlantic, 2 = Tropical Atlantic, 3 = Mediterranean, 4 = Temperate North Pacific, 5 = Tropical Indo-Pacific, 6 = Temperate Southern Oceans); population trend (Pop. Trend); trajectory of seagrass distribution change in % per annum (Traj%) and number of studies used to determine the trajectory based on NCEAS population data. Blank cells indicate lack of information. *Data Deficient species in need of urgent research.

Family	Species name	Red List Category; Criteria	Gen. length	Min. depth	Max. depth	Depth range	Bioregion	Pop. trend	Traj% (# studies)
ZOSTERACEAE	*Phyllospadix japonicus*	EN; A2, B1	6	0	8	8	4	Decreasing	
ZOSTERACEAE	*Zostera chilensis*	EN;B2		1	7	6	6	Decreasing	
ZOSTERACEAE	*Zostera geojeensis*	EN; B2		3	5	2	4	Decreasing	
HYDROCHARITACEAE	*Halophila baillonii*	VU; B2	1	0	15	15	2	Decreasing	
HYDROCHARITACEAE	*Halophila beccarii*	VU; B2	1	0	1	1	5	Decreasing	
HYDROCHARITACEAE	*Halophila hawaiiana*	VU; A2	2	2	2	0	5	Decreasing	
POSIDONIACEAE	*Posidonia sinuosa*	VU; A2	20	1	15	15	6	Decreasing	−1.2 (11)
ZOSTERACEAE	*Phyllospadix iwatensis*	VU; B1	6	0	5	5	4	Decreasing	
ZOSTERACEAE	*Zostera capensis*	VU; B1	4	0	6	6	5,6	Decreasing	
ZOSTERACEAE	*Zostera caespitosa*	VU; B1	1	3	8	5	4	Decreasing	
HYDROCHARITACEAE	*Halophila engelmanni*	NT		0	18	18	2	Decreasing	
HYDROCHARITACEAE	*Halophila nipponica*	NT	4	0	8	8	4	Decreasing	
POSIDONIACEAE	*Posidonia australis*	NT	5	0	22	22	6	Decreasing	−1.8 (18)
ZOSTERACEAE	*Zostera asiatica*	NT	5	8	15	7	4	Decreasing	
ZOSTERACEAE	*Zostera caulescens*	NT	2	3	16	13	4	Decreasing	
CYMODOCEACEAE	*Amphibolis antarctica*	LC	10	1	22	21	6	Stable	
CYMODOCEACEAE	*Amphibolis griffithii*	LC	10	1	56	55	6	Stable	−0.8 (2)
CYMODOCEACEAE	*Cymodocea angustata*	LC		1	7	6	5	Unknown	
CYMODOCEACEAE	*Cymodocea nodosa*	LC	3	0	40	40	1,3	Stable	0.6 (1)
CYMODOCEACEAE	*Cymodocea rotundata*	LC		0	10	10	5	Stable	
CYMODOCEACEAE	*Cymodocea serrulata*	LC		0	25	25	5	Stable	
CYMODOCEACEAE	*Halodule pinifolia*	LC	3	0	7	7	5	Decreasing	
CYMODOCEACEAE	*Halodule uninervis*	LC	3	0	20	20	5	Stable	
CYMODOCEACEAE	*Halodule wrightii*	LC	3	0	18	18	1,2,3,4,5	Increasing	2 (1)
CYMODOCEACEAE	*Syringodium filiforme*	LC	3	0	20	20	2,3	Stable	
CYMODOCEACEAE	*Syringodium isoetifolium*	LC		0	15	15	5,6	Stable	
CYMODOCEACEAE	*Thalassodendron ciliatum*	LC	8	0	33	33	5,6	Unknown	
CYMODOCEACEAE	*Thalassodendron pachyrhizum*	LC	10	2	60	58	6	Unknown	
HYDROCHARITACEAE	*Enhalus acoroides*	LC		0	5	5	5	Decreasing	
HYDROCHARITACEAE	*Halophila australis*	LC	4	1	15	14	6	Stable	
HYDROCHARITACEAE	*Halophila capricorni*	LC		21	54	33	5	Unknown	
HYDROCHARITACEAE	*Halophila decipiens*	LC	1	0	58	58	2,3,4,5,6	Increasing	
HYDROCHARITACEAE	*Halophila johnsonii*	LC		1	4	4	2	Increasing	
HYDROCHARITACEAE	*Halophila minor*	LC		0	7	7	5	Unknown	
HYDROCHARITACEAE	*Halophila ovalis*	LC	4	0	20	20	4,5,6	Stable	
HYDROCHARITACEAE	*Halophila ovata*	LC		0	20	20	5	Stable	
HYDROCHARITACEAE	*Halophila spinulosa*	LC	2	0	60	60	5	Stable	
HYDROCHARITACEAE	*Halophila stipulacea*	LC	1	0	70	70	2,3,5	Increasing	
HYDROCHARITACEAE	*Halophila tricostata*	LC	0.5	0	45	45	5	Unknown	
HYDROCHARITACEAE	*Thalassia hemprichii*	LC	6	0	5	5	5	Stable	
HYDROCHARITACEAE	*Thalassia testudinum*	LC	8	0	10	10	2	Stable	
POSIDONIACEAE	*Posidonia angustifolia*	LC	5	2	50	48	6	Stable	
POSIDONIACEAE	*Posidonia coriacea*	LC	15	2	35	33	6	Stable	0.4 (1)
POSIDONIACEAE	*Posidonia denhartogii*	LC	15	2	35	33	6	Stable	
POSIDONIACEAE	*Posidonia kirkmanii*	LC	15	2	40	38	6	Stable	
POSIDONIACEAE	*Posidonia oceanica*	LC	35	1	45	45	3	Decreasing	−5 (10)
POSIDONIACEAE	*Posidonia ostenfeldii*	LC	15	5	30	25	6	Unknown	
RUPPIACEAE	*Ruppia cirrhosa*	LC	1				3	Stable	−23.1 (1)
RUPPIACEAE	*Ruppia maritima*	LC	1	0	1	1	1,2,3,4,5,6	Stable	
RUPPIACEAE	*Ruppia megacarpa*	LC	1				6	Stable	
RUPPIACEAE	*Ruppia polycarpa*	LC	1				6	Stable	
RUPPIACEAE	*Ruppia tuberosa*	LC	1				6	Stable	
ZOSTERACEAE	*Phyllospadix scouleri*	LC	6				4	Stable	
ZOSTERACEAE	*Phyllospadix serrulatus*	LC	6				4	Stable	
ZOSTERACEAE	*Phyllospadix torreyi*	LC	6	0	7	7	4	Stable	
ZOSTERACEAE	*Zostera muelleri*	LC	2	0	7	7	5,6	Stable	−56.7 (3)
ZOSTERACEAE	*Zostera nigricaulis*	LC		0	15	15	6	Decreasing	
ZOSTERACEAE	*Zostera polychlamys*	LC		1	48	47	6	Stable	
ZOSTERACEAE	*Zostera tasmanica*	LC	1	0	12	12	6	Stable	
ZOSTERACEAE	*Zostera japonica*	LC	1	0	3	3	4,5	Increasing	
ZOSTERACEAE	*Zostera noltii*	LC	1	0	10	10	1,3	Decreasing	
ZOSTERACEAE	*Zostera marina*	LC	1	2	15	13	1,3,4	Decreasing	−1.4 (126)
ZOSTERACEAE	*Zostera pacifica*	LC	1	0	20	20	4	Unknown	
CYMODOCEACEAE	*Halodule bermudensis*	DD*	2	0	18	18	2	Decreasing	
CYMODOCEACEAE	*Halodule ciliata*	DD*					2	Unknown	
CYMODOCEACEAE	*Halodule emarginata*	DD*					2	Unknown	
CYMODOCEACEAE	*Halodule beaudettei*	DD	2				2	Unknown	

(*continued on next page*)

Table 2 (*continued*)

Family	Species name	Red List Category; Criteria	Gen. length	Min. depth	Max. depth	Depth range	Bioregion	Pop. trend	Traj% (# studies)
RUPPIACEAE	*Ruppia filifolia*	DD	1	0	46	46	6	Unknown	
ZANNICHELLIACEAE	*Lepilaena australis*	DD		0	1	1	6	Unknown	
ZANNICHELLIACEAE	*Lepilaena marina*	DD		0	2	2	6	Unknown	
HYDROCHARITACEAE	*Halophila euphlebia*	DD*	4	0	20	20	4	Unknown	
HYDROCHARITACEAE	*Halophila sulawesii*	DD*		10	30	20	5	Unknown	

Fig. 2. Clockwise from upper left: (a) *Phyllospadix japonicus*, an Endangered seagrass species, in the rocky surf zone in South Korea (Photo credit: Kun–Seop Lee); (b) Shrimp aquaculture ponds built along the shore destroy mangroves and the Vulnerable seagrass *Halophila beccarii* (detail insert) in Pantai Baru, Kelantan, Peninsular Malaysia (Photo credit: Japar Sidik Bujang); (c) The Vulnerable species *Zostera caespitosa* surrounded by nuisance seaweed adjacent to an aquaculture farm in China (Photo credit: Fred Short); (d) Gleaning for small shellfish in a meadow of the Vulnerable seagrass species *Zostera capensis* in Mozambique (Photo credit: Salomão Bandeira).

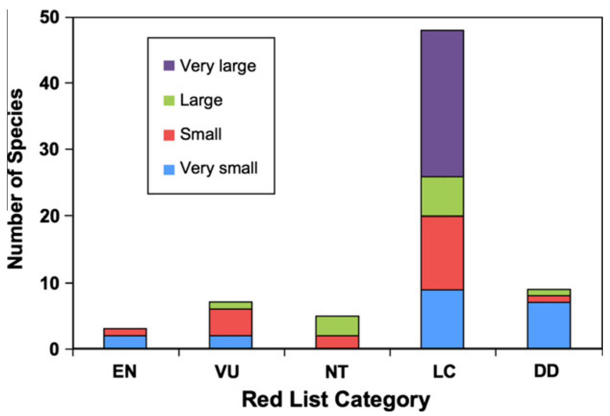

Fig. 3. The number of seagrass species in Red List Categories, Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC), Data Deficient (DD), by relative distribution size based on species' area of occupancy: Very small 0–25,000 km^2, Small 26,000–75,000 km^2, Large 76,000–200,000 km^2, and Very large > 200,000 km^2.

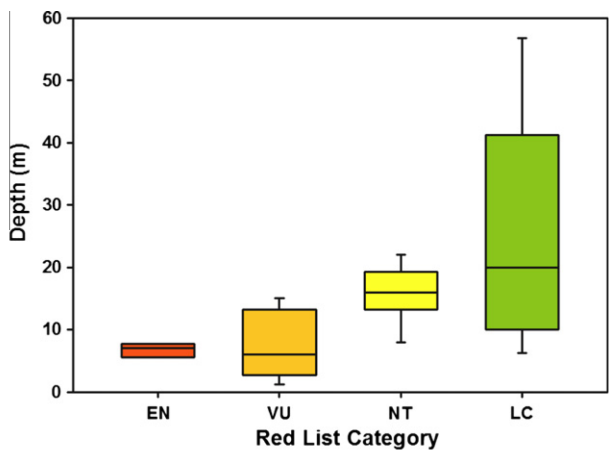

Fig. 4. Maximum depths of seagrass species in Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC) categories as a box plot. Threatened species (EN and VU) significantly different from non-threatened (NT and LC); Kruskall–Wallace Chi-square = 12.63, $df = 3$, $p < 0.01$.

H. beccarii, has a relatively large range in the Tropical Indo-Pacific (Green and Short, 2003) but is very patchily distributed with a low area of occupancy, as it is only found in the intertidal zone, where it is impacted by near-shore human activities (IUCN, 2010). The five species listed as Near Threatened generally have larger ranges than the Vulnerable seagrasses, although all are experiencing population decline (Table 2).

Seagrass species have depth ranges between 1 and 70 m. However, for threatened and Near Threatened species the depth range was significantly narrower (Table 2), compared to non-threatened species ($t = -3.317$, $df = 55$, $p < 0.01$), and there were significant differences in maximum depths between the threatened and non-threatened Red List Categories (Fig. 4). Seagrass recruitment rates (generation length) ranged from 0.5 to 35 years (Table 2), with no significant difference between recruitment rates of threatened vs. non-threatened species (Mann Whitney Wilcoxon = 925, $p = 1$). Recruitment rates are lacking for many seagrass species; more information on recruitment rates will improve the accuracy of Red List designations.

3.2. Least concern and data deficient species

Forty-eight species (67%) were listed as Least Concern and nine others (12.5%) as Data Deficient. The majority of species listed as Least Concern were experiencing area loss, as seagrass area continues to decline in many parts of the world (Waycott et al., 2009). Some species of Least Concern may be locally threatened, but their population decline was estimated to be well below the IUCN threatened category thresholds. *Zostera marina*, for example, has severely declined in some of its former range (e.g., San Francisco Bay, the Wadden Sea, Chesapeake Bay, and other European, Asian and US locations) but is still widespread elsewhere and thrives in less developed and clear-water areas (Short and Wyllie-Echeverria, 1996; Green and Short, 2003). The majority of the Least Concern species are wide-ranging with large distributions (Table 2 and Fig. 3), and the consensus of expert opinion was that many are resistant to heavy disturbance, are fast growing, or have rapid recruitment rates.

The IUCN Categories and Criteria could not be applied to the nine species listed as Data Deficient due to a lack of information on taxonomy, distribution, population status or threats. Species listed as Data Deficient may qualify for a threatened category when further information is available. In particular, five Data Deficient species (*Halodule bermudensis*, *Halodule ciliata*, *Halodule emarginata*, *Halophila euphlebia*, and *H. sulawesii*) may be classified in a threatened category in the near future if further research confirms their relatively small distributions and the presence of intensive threats. One Data Deficient species, *H. ciliata*, may already be extinct, as it was last collected in 1916 at Taboga Island, Panama (den Hartog, 1960) and has not been found in recent years.

3.3. Global distribution of seagrass species and extinction risk

In general, tropical regions support the greatest diversity of seagrass species (Hemminga and Duarte, 2000; Short et al., 2007). Seagrasses are also found, at the limits of their northern distribution, in temperate waters including Norway, Russia and Alaska and, at their most southerly distribution, in Chile (Short et al., 2007). The Coral Triangle, located within the Tropical Indo-Pacific bioregion, has high seagrass species diversity with 16 species in the Triangle and up to 25 in the bioregion. The Tropical Indo-Pacific bioregion (Table 3) has the highest percentage of species where trends in population are unknown (24%). Seagrass species richness is also high off the southwest coast of Australia (Fig. 5a), although some of these species may be an artifact of taxonomy that has yet to be settled by definitive methods. Two endemic species in southern Australia, *P. sinuosa* listed as Vulnerable and *P. australis* listed as Near Threatened, are slow-growing with low recruitment rates and suffer annual population declines of 1.2% and 1.8%, respectively (Waycott pers. obs. 2009). Globally, the lowest seagrass diversity is in the Temperate North Atlantic bioregion, with only five seagrass species, all of which are listed as Least Concern, primarily due to their very large range sizes, although two have declining population trends (*Z. marina* and *Zostera noltii*).

The Temperate North Pacific bioregion has the highest number and percentage (Table 3) of threatened and Near Threatened species, with up to 100% of species in some areas of China, Korea, and Japan in threatened or Near Threatened categories (Fig. 5b). Although the overall number of species in the Temperate North Atlantic and Mediterranean bioregions is much lower than in the Temperate North Pacific, these bioregions do not have any seagrass species in threatened or Near Threatened categories (Table 3). However, in both of these regions, 34–40% of seagrass species show decreasing population trends. For example, the Mediterranean endemic *Posidonia oceanica*, listed as Least Concern, has declined approximately 10% over the last 100 years due to mechanical damage from trawling and boats, coastal development and eutrophication, but this rate does not meet the threshold for a threatened category.

3.4. Population trends

Twenty-two seagrass species (31%) have declining populations, including all species listed as threatened (Endangered or Vulnerable) or Near Threatened, and six seagrass species listed as Least Concern (Table 1). Twenty-nine of 72 species (40%) have a stable population (i.e., not decreasing or increasing globally), and five species (7%), all listed as Least Concern, show an increasing population (Waycott et al., 2009; IUCN, 2010). Two of the increasing species (*Halophila stipulacea* and *Zostera japonica*) have recently expanded across the Atlantic and Pacific, respectively, to new locations where they have spread rapidly (Short et al., 2007; Willette and Ambrose, 2009). Population trends for sixteen species are unknown (eight Least Concern and eight Data Deficient).

Declining seagrass species are found worldwide, particularly north of the equator (Fig. 5c) in the most developed parts of the world, but also in Australia and throughout the Indo-Pacific bioregion except for remote islands and areas of low development. The highest concentration of declining species is in China, Korea and Japan (Fig. 5c), which have heavily developed coasts with extensive shoreline reclamation where 80–100% of all seagrass species are in decline (Green and Short, 2003). As these areas are high in seagrass species richness (Fig. 5a), large numbers of species in this region are threatened or Near Threatened (Fig. 5b).

In Southeast Asia, a Vulnerable seagrass species (*H. beccarii*) as well as several species of Least Concern are in decline as a result of aquaculture (Fig. 2b), artisanal fisheries and heavy watershed siltation. In southern Australia, *P. sinuosa* (Vulnerable)

Table 3
Number (percent) of seagrass species for each Red List Category and for population trends, by bioregion (Short et al., 2007).

Bioregion (no. species)	Red List Categories				Population trends			
	Threatened	NT	LC	DD	Decreasing	Stable	Increasing	Unknown
1. Temperate North Atlantic (5)	0	0	5(100%)	0	2(40%)	2(40%)	1(20%)	0
2. Tropical Atlantic (13)	1(8%)	1(8%)	7(54%)	4(31%)	3(23%)	4 (31%)	3(23%)	3(23%)
3. Mediterranean (9)	0	0	9(100%)	0	3(34%)	4 (44%)	2(22%)	0
4. Temperate North Pacific (18)	4(22%)	3(17%)	10(56%)	1(6%)	8(44%)	5(28%)	3(17%)	2(11%)
5. Tropical Indo-Pacific (25)	3(12%)	0	21(84%)	1(4%)	5(20%)	11(44%)	3(12%)	6(24%)
6. Temperate Southern Oceans (28)	3(11%)	1(4%)	21(75%)	3(11%)	5(18%)	16(57%)	1(4%)	6(21%)

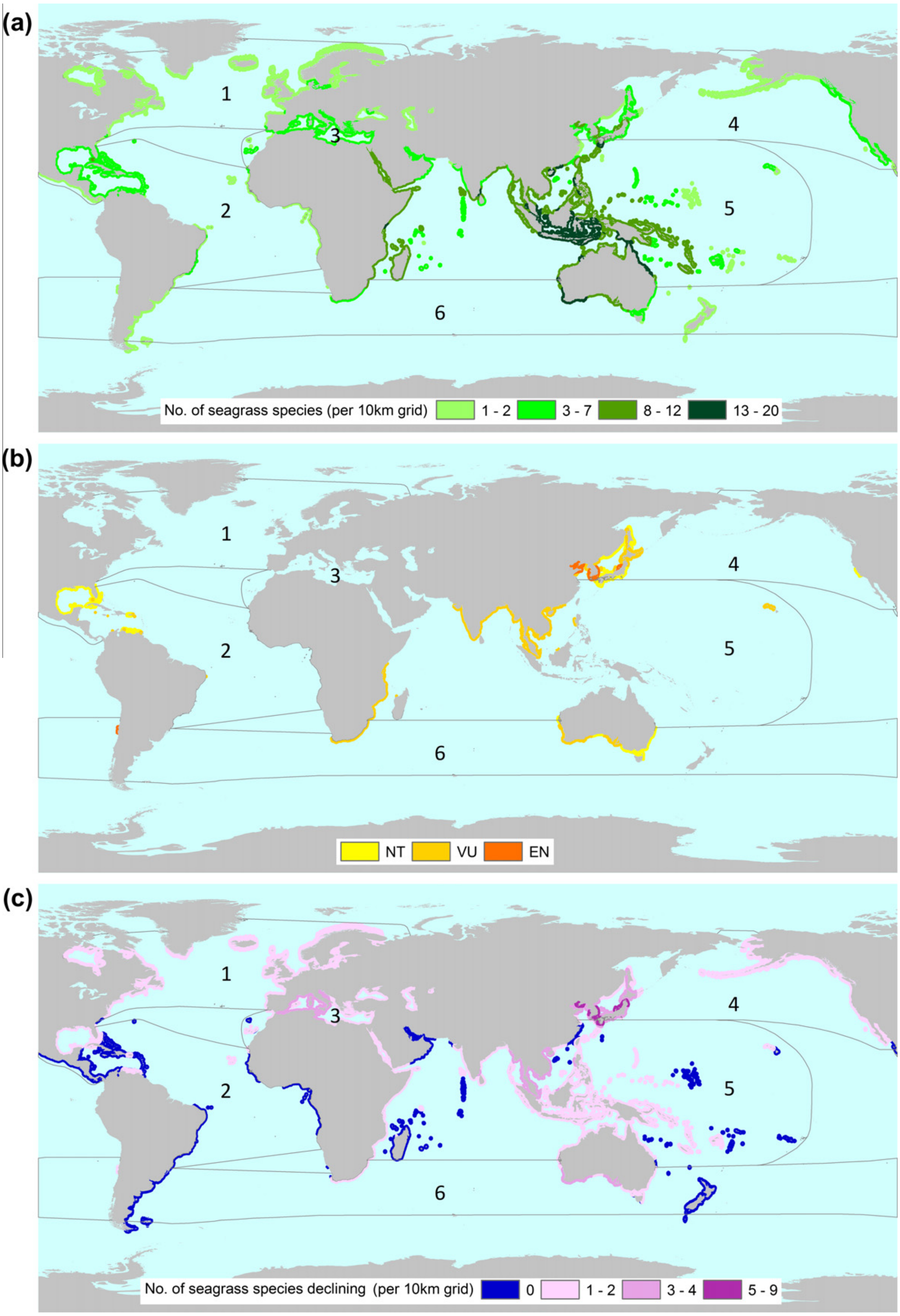

Fig. 5. Global distribution of (a) seagrass species richness; (b) distribution of the 15 threatened or Near Threatened seagrass species (NT overlaid by VU overlaid by EN); (c) number of seagrass species in stable and declining population trends. Numbers 1–6 indicate bioregion (Short et al., 2007). Red List Categories: Endangered (EN), Vulnerable (VU), and Near Threatened (NT); Data Deficient (DD) species not included.

and *P. australis* (Near Threatened) are in decline, as are two species of Least Concern. In the Mediterranean bioregion, there are nine seagrasses; in some areas of the western Mediterranean, 4 of 5 species present are in decline, though of Least Concern. Such areas, with a high proportion of species in decline, need priority regional conservation, even when globally the species are not in threatened categories.

3.5. Threats to seagrass species

Coastal areas occupied by seagrass habitat face myriad threats (Short and Wyllie-Echeverria, 1996; Lotze et al., 2006). The coastal ocean is under pressure from human development and manipulation and seagrass loss occurs as a result of pollution and habitat destruction (Fig. 2c), although seagrasses as a group have a lower proportion of threatened or Near Threatened species (21%) compared to other marine habitat species such as the reef-building corals (48% in threatened or Near Threatened categories; Carpenter et al., 2008), or mangroves (26% in threatened or Near Threatened categories; Polidoro et al., 2010).

Globally, the primary impact to seagrasses is loss of water clarity and quality due to both eutrophication, i.e., phytoplankton and nuisance seaweed blooms (Burkholder et al., 2007), and sediment loading, i.e., suspended sediments and siltation (Dennison et al., 1993; de Boer, 2007). Seagrass beds are destroyed by coastal construction, land reclamation, shoreline hardening, and dredging (Erftemeijer and Lewis, 2006); damaging fisheries practices such as trawling and aquaculture (Pergent-Martini et al., 2006) also harm seagrass habitats. Mechanical damage from boats, boat moorings, and docks is a problem in some regions (Burdick and Short, 1999; Kenworthy et al., 2002), as are introduced species (Williams, 2007) that compete for space and resources (Heck et al., 2000). Diseases, such as wasting disease, threaten some seagrasses and have caused large-scale declines (Rasmussen, 1977; Short et al., 1986). Many of the threats are cumulative and some are not mutually exclusive (e.g., most coastal development affects water quality). The effects of global climate change on seagrasses are just beginning to be understood (Short and Neckles, 1999; Waycott et al., 2007; Palacios and Zimmerman, 2007; Björk et al., 2008); however, localized impacts to seagrass species will decrease their survival capacity in the face of global threats.

The most common threat to seagrasses is human activity, comprising all of the threats listed above except herbivory and disease, and affecting 67 species (93%), 14 of which (21%) were listed in threatened or Near Threatened categories (Table 4). For species with small spatial ranges, coastal development can be devastating. With further urbanization of coastal areas and ever-greater human populations, coastal development is only expected to increase, along with corresponding declines of seagrass and other estuarine and coastal species (Lotze et al., 2006).

Table 4
The number of seagrass species (percent of 72 species) affected by each identified major threat category, as assigned by expert opinion. Extinction risk or Ext. Risk (in either threatened or Near Threatened categories): number of species (percent of affected species) for which the threat was present and causing elevated extinction risk. No extinction risk or No Ext. Risk: number of species (percent of affected species) for which the threat was present, but not causing an elevated extinction risk. Unknown extinction risks are not shown. Threat categories are not mutually exclusive; e.g., water quality can be degraded by coastal development.

Major threat category	Total species affected	Ext. risk	No ext. risk
Coastal development	67 (93%)	14 (21%)	46 (69%)
Degraded water quality	42 (58%)	11 (26%)	28 (67%)
Mechanical damage	32 (44%)	3 (9%)	25 (78%)
Aquaculture	28 (39%)	4 (14%)	22 (79%)
Fisheries	27 (38%)	1 (4%)	23 (85%)
Excess siltation/ sedimentation	26 (36%)	3 (12%)	20 (77%)
Competition	5 (7%)	2 (40%)	3 (60%)
Disease	2 (3%)	0 (0%)	2 (100%)

Forty-one seagrass species (57%) are affected by degraded water quality, 11 of which (27%) are in threatened or Near Threatened Red List categories. Light reduction through increased growth of phytoplankton and macroalgae during eutrophication is the most common cause of seagrass decline in temperate waters while in tropical oceans, sediment loading is likely the largest water clarity impact (Freeman et al., 2008; Duarte et al., 2008). Mechanical damage, aquaculture, fisheries activities, and burial by sediments affected 35–44% of species. Competition from other marine species affected only five seagrasses (7%) two of which, *H. beccarii* and *H. hawaiiana*, are listed as Vulnerable; the former competes with native intertidal seaweed populations and the latter with invasive seaweeds. Only two species, *Z. marina* and *Thalassia testudinum*, have been impacted by endemic disease to the extent of causing population decline.

3.6. Impacts of seagrass extinction risk to other species

The loss of seagrass species, especially in areas with low seagrass diversity or with limited seagrass distribution, will have severe impacts on marine biodiversity, the health of other marine ecosystems, and the human livelihoods that depend on both nearshore and pelagic marine resources (Hughes et al., 2009). There are currently 115 marine species that live in seagrass habitat that have been assessed under IUCN Red List Criteria (IUCN, 2010), including some invertebrates, fishes, sea turtles, and marine mammals. Of these, 31 (27%) are in threatened categories (nine Critically Endangered, seven Endangered and 15 Vulnerable). In a number of cases, loss of seagrass habitat and degradation of seagrass beds is stated as a major contributor to the threatened status of these species.

For the many other marine species yet to be assessed that are dependent on or associated with seagrasses, the newly available seagrass species Red List assessments will provide critical information. Effects on other species at risk are exemplified by the link between seagrasses and their direct grazers including sirenia and turtles; e.g., in Placencia Lagoon, Belize the Vulnerable seagrass *H. baillonii* is a major food source for the Vulnerable manatee (*Trichechus manatus*), while the Vulnerable seagrass *H. hawaiiana*, endemic to the Hawaiian Islands, is fed on by the Endangered green turtle (*Chelonia mydas*).

3.7. Impacts of seagrass extinction risk to humans

Loss of livelihood and food resources in less developed parts of the world are directly linked to reduced seagrass habitats, where gleaning and fishing on the seagrass flats is a major source of protein (Unsworth and Cullen, 2010). For example, in East Africa the intertidal collection of bivalves and snails (Fig. 2d) is made daily at low tide in the Vulnerable *Z. capensis* meadows (Bandeira and Gell, 2003). In nations with a vast human demand for seafood such as Korea, Japan, and China, the threatened and Near Threatened status of some important seagrasses (*Ph. iwatensis, Ph. japonicus, Z. asiatica, Z. caespitosa, Z. caulescens* and *Z. geojeensis*) means further loss of fisheries resources as these seagrasses provide nursery grounds and habitat for commercially important fish species (Aioi and Nakaoka, 2003; Lee and Lee, 2003; Shi et al., 2010). Most seagrass species in the threatened and Near Threatened Red List categories have small ranges and, if they became extinct or moved to more threatened categories, would likely have a relatively small direct impact on human populations. It is the overall decline of seagrass habitat health worldwide (Waycott et al., 2009) that is the greatest threat to humans, causing losses of fisheries health, water quality, shoreline stability, and ecosystem richness (Duarte et al., 2008).

3.8. Recommendations: what to do about species at risk

Substantial amelioration of poor water clarity to the point of reversing seagrass species declines will require major efforts to reduce run-off, as well as sediment and nitrogen loading. Eleven of the 15 threatened and Near Threatened species are at risk from loss of water clarity, including four *Zostera* species, the two *Posidonia* species, and four of the five *Halophila* species (Tables 2 and 4). In all cases, improving water clarity by decreasing both point and non-point sources of pollution and sediments will reduce the risk of extinction for these species. Improved coastal development practices are needed worldwide along with increased conservation (Kenworthy et al., 2006).

The Endangered seagrass species, although affected to some degree by reduced water clarity, have suffered from more direct impacts. Of the three Endangered seagrasses loss of area of occurrence for *Ph. japonicus* (IUCN, 2010) and *Z. geojeensis* (Shin et al., 2002) is directly linked to near-shore construction, while the cause of loss in *Z. chilensis* is unknown (Phillips et al., 1983). Endangered seagrasses require recognition and protection of existing populations, with removal of direct risks in each case, including creation of marine protected areas (Hoffmann et al., 2010) and limits on coastal construction.

Direct human impacts affect two Vulnerable species of seagrass: *H. beccarii* and *Z. capensis*. *H. beccarii* is commonly associated with mangrove forests in the Tropical Indo-Pacific bioregion and the extensive clearing of mangroves for shrimp aquaculture ponds has resulted in reduction of its distribution (Fig. 2b). Restrictions on mangrove clearing as well as mangrove restoration are needed to improve the status of *H. beccarii*. *Z. capensis* in the western Indo-Pacific is another case of human food production impacting habitat, where direct destruction is caused by gleaning, trampling and excavation of shellfish by digging (Fig. 2d). A measure as simple as teaching the fishers to minimize seagrass destruction in their harvesting process could improve the prospects of this Vulnerable species.

4. Conclusion

One in five seagrass species is now listed as Endangered, Vulnerable, or Near Threatened, having a heightened risk of extinction under the IUCN Red List Criteria. The threatened categories serve to set priority measures for biodiversity conservation. Many seagrass species need further investigation to better understand their risk of extinction as well as their distribution, life history, and recruitment rates, in particular those species in Near Threatened and Data Deficient categories. One-third of seagrass species are in decline globally, even if the declines are not great enough to trigger a threatened Red List category. In the big picture, our findings elevate the seagrass crisis brought on through anthropogenic impacts by, for the first time, demonstrating the threat to seagrass biodiversity. Clearly, seagrass species at risk of extinction and the worldwide seagrass habitat require conservation and restoration. Beyond seagrasses themselves, there are many threatened species that depend on seagrass habitat for food, shelter, and nursery areas. These include the dugong (*Dugong dugon* with a Red List status of Vulnerable), green sea turtle (*C. mydas*, Endangered), and Cape seahorse (*Hippocampus capensis*, Endangered).

The species level assessment of seagrass extinction risk shows that, while many threats are localized or regional, such threats significantly contribute to global seagrass population declines. Species level assessments are useful for identifying those species in need of immediate conservation measures, and helping to raise both awareness and funding, targeted at regions and species with exceptional threats. To stop and then reverse the decline of seagrass species, a powerful combination of reduced exploitation, habitat protection and monitoring, and improved water clarity is needed. Both policy and action are imperative to protect seagrass habitats and species from degradation and extinction.

Acknowledgements

We thank Tom Haas and the New Hampshire Charitable Foundation for their generous support of SeagrassNet and the IUCN Global Marine Species Assessment through Conservation International. We thank C. Short for editing, and the following scientists for their contributions: G. Abrusci, A. Calladine, G. di Carlo, K. Coates, A. Cuttelot, C. Duarte, J. Fourqurean, J. L. Gaeckle, C. den Hartog, H. Harwell, K. Heck, M. Hoffmann, A. R. Hughes, X. D. Lewis, S. McKenna, R. McManus, S. Olyarnik, S. Sarkis, J. Herrera Silveria, J. Smith, W. Turner, and S. L. Williams. Also thanks to: J. Smith and D. Thornham (for statistical help), M. Alava, M. Polamar and L. Casten (for assisting with the Philippines workshop), D. Pollard, C. Dawes and A. Mathieson (for review), Royal Caribbean Cruises Ocean Fund (for contributions to the Tropical Atlantic species workshop), First Philippine Conservation Incorporated (for contributions to the Tropical Indo-Pacific species workshop), National Center for Ecological Analysis and Synthesis (for hosting the Temperate species workshop), and Global Seagrass Trajectories Database Working Group (NCEAS). Jackson Estuarine Laboratory contribution number 500, UMCES contribution number 4499, and VIMS contribution number 3136.

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