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Seagrass ecosystem contributions to people's quality of life in the Pacific Island Countries and Territories

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ABSTRACT

Seagrass ecosystems provide critical contributions (goods and perceived benefits or detriments) for the livelihoods and wellbeing of Pacific Islander peoples. Through in-depth examination of the contributions provided by seagrass ecosystems across the Pacific Island Countries and Territories (PICTs), we find a greater quantity in the Near Oceania (New Guinea, the Bismarck Archipelago and the Solomon Islands) and western Micronesian (Palau and Northern Marianas) regions; indicating a stronger coupling between human society and seagrass ecosystems. We also find many non-material contributions historically have been overlooked and under-appreciated by decision-makers. Closer cultural connections likely motivate guardianship of seagrass ecosystems by Pacific communities to mitigate local anthropogenic pressures. Regional comparisons also shed light on general and specific aspects of the importance of seagrass ecosystems to Pacific Islanders, which are critical for forming evidence-based policy and management to ensure the long-term resilience of seagrass ecosystems and the contributions they provide.

1. Introduction

Seagrass ecosystems are extensive throughout the Pacific Island Countries and Territories (PICTs) region and occur in most PICTs (except Cook Islands, Nauru, Niue, Pitcairn Islands, Tuvalu), covering an estimated 1446.2 km^2 (McKenzie et al., 2021). These productive meadows are globally recognised for their support for human livelihoods and how they help regulate our environment (Cullen-Unsworth et al., 2014; Unsworth et al., 2018b; Waycott et al., 2011). Among the numerous ecosystem contributions, seagrass meadows globally also support high biodiversity which includes charismatic megafauna such as the dugong (*Dugong dugon*) and green sea turtle (*Chelonia mydas*).

Western-science has traditionally viewed the relationship between people and nature through the concept of 'ecosystem services' (ES) (i.e.

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ecological goods and services, environmental services, nature's services) (Costanza et al., 1997; Costanza et al., 2017). More recently, to capture and facilitate engagement with a wider diversity of worldviews, knowledge systems and stakeholders, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) introduced the term Nature's Contributions to People (NCP), defined as 'the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems and their associated ecological and evolutionary processes) to people's quality of life' (Díaz et al., 2018). NCP is now used as a supra-concept to ES (Kadykalo et al., 2019). The fundamental difference in the NCP conceptual framework, is that culture permeates through and across all elements (nature, quality of life, co-production, direct and indirect drivers of change) and components (regulating, material, non-material) (Díaz et al., 2018), rather than being confined to an often isolated category as in the Millennium Assessment (MEA, 2005) framework (Kadykalo et al., 2019). A key attribute of the NCP framework is the inclusion of traditional ecological knowledge (TEK), which is considered a collaborative concept that bridges cross-cultural and cross-situational divides, and provides Indigenous and other traditional understandings of the relationships among living things and their environments (Whyte, 2013). In the PICTs the contribution of seagrasses to human wellbeing is thought to make them a high conservation priority (Cullen-Unsworth and Unsworth, 2013; Unsworth and Cullen, 2010; Unsworth et al., 2019; Unsworth et al., 2018a), especially given the extensive nature of their distribution and the very close coupling of human societies with the marine environment. Despite this apparent importance, the seagrass ecosystem contributions for this region have previously been given little attention within the academic literature, limiting the ability of management agencies to make evidence-based policy decisions regarding their governance.

The close coupling of Pacific Island peoples with the marine environment has developed over millennia and likely shaped their view on nature and influenced their cultural identity. Based largely on linguistics, archaeology, artifacts (e.g. pottery), radiocarbon dating, and genetics, there are three broad cultural/ethnic groups that settled and principally reside in three regions of the Pacific Islands today: Melanesia, Micronesia and Polynesia (Fig. 1). Melanesia is the oldest inhabited region, being settled between 13,000 and 47,000 years ago, whereas Polynesia is the youngest being settled more recently, beginning 3000 and 5000 years ago (Kirch, 2017).

Melanesia has incurred two waves of settlement history. Its initial occupation with peoples departing from Asia 40,000–60,000 years ago, only reached as far as mainland New Guinea, the Bismarck Archipelago and the northern Solomon Islands (aka Near Oceania) (Kayser, 2010; Keppel et al., 2014). The second wave originated from Taiwan ~5000 years ago, when Lapita seafarers rapidly migrated through Near Oceania to settle in the eastern parts of the region (Remote Oceania) ~2000 to 3000 years ago (Benton et al., 2012; Kirch, 2017). Micronesia has a three-part sequence of settlement history; the earliest being in the western archipelagos (Palau and Marianas) between 1200 and 3500 years ago from the Philippines, followed by movement into Yap from the Bismarck Archipelago (PNG) about 1800 years ago, and the central – eastern Federated States of Micronesia from the Solomon - Vanuatu region around 900 to 2200 years ago (Kirch, 2017).

The settlement of Polynesia is the most complex, with Taiwanese migrants departing western Indonesia about 4000 years ago, eventually settling in Tonga and Samoa around 3000 years ago, and then slowly moving eastward to what is now the Society Islands (French Polynesia) (Benton et al., 2012). A second, broader, series of migrations then occurred between 1100 and 600 years ago, beginning with a westward movement to the Cook, Niue, Tokelau, and Tuvalu Islands. This was followed by northward migration to the Marquesas (and Hawaiian) Islands, an eastward movement to Tuamotu (French Polynesia) and Pitcairn Islands, a southward movement to the Austral and Gambier Islands (French Polynesia), and finally northwestward movement towards the Carolines, Fiji, northern Solomon Islands, and northern Papua New Guinea, including islands previously settled by Melanesians and Micronesians (Maragos and Williams, 2011).

Although we have defined three distinct Pacific Island regions, we acknowledge Melanesia (and, to a lesser degree, Micronesia) is more a

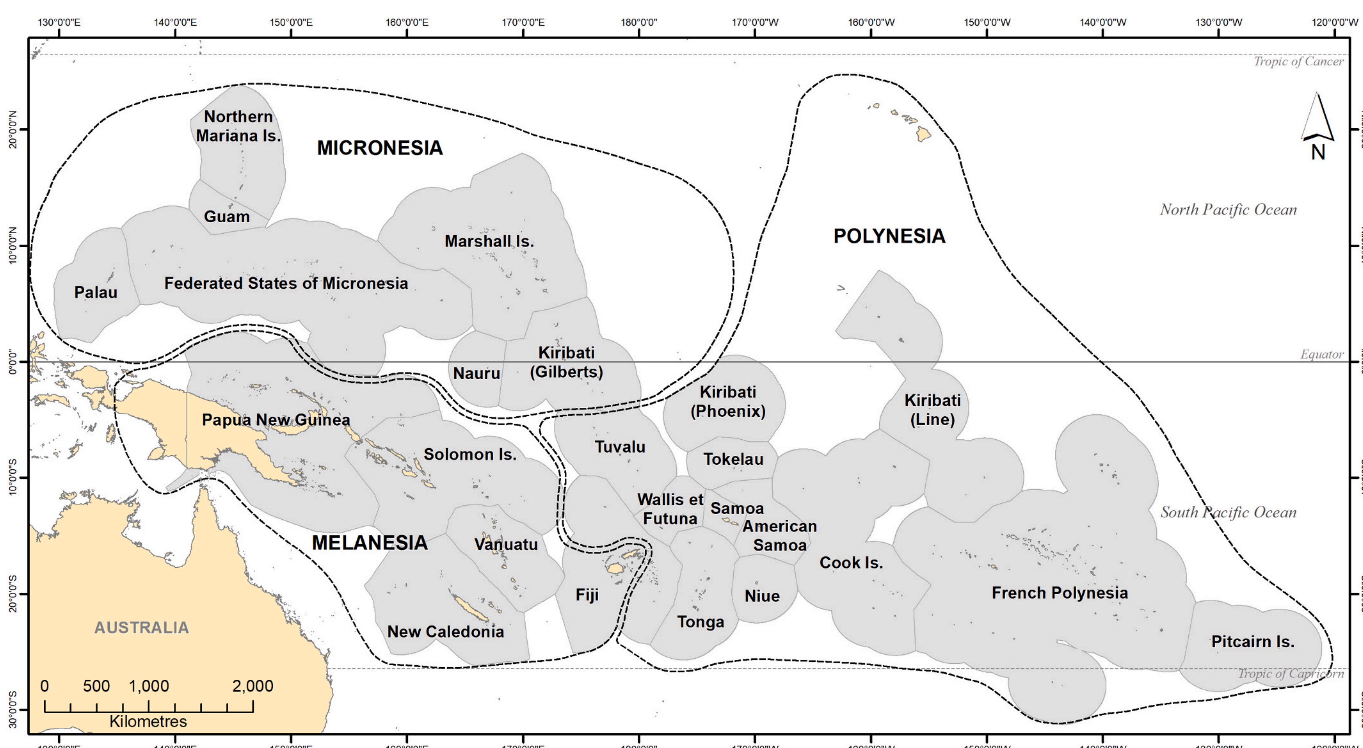

Fig. 1. Pacific Island Countries and Territories (PICTs) and their Exclusive Economic Zones (EEZ). Ethno-geographic delineation based on Taylor and Kumar (2016) and Burley (2013).

geographic region and its inhabitants do not necessarily represent cultural unity; as opposed to Polynesians who have been shown to represent a more homogeneous group of people (Kayser, 2010). At the country/territory level, we recognise people of different ethnic origins within the main cultural groups, including Polynesians and Micronesians within Melanesia (e.g. Rotuma, Lau, Rabi and Kiaoa in Fiji) and Polynesians within Micronesia (e.g. Kapingamarangi and Nukuoro in Pohnpei, FSM, Rotumans in Kosrae, FSM), and Micronesians and Polynesians within Melanesia (e.g. Gilbertese and Tikopians in the Solomon Islands).

In recognition of the close coupling of Pacific Islanders to nature, we examine variation in seagrass ecosystem contributions to people (SCPs) within and between regions, using a combination of standardised framework components, originating from the Millennium Assessment (MEA, 2003, 2005), through to the IPBES (Díaz et al., 2018) (Table S1). This approach builds on the classifications used by de Groot et al. (2002) and Nordlund et al. (2016) to collate and evaluate SCPs from a generalizing perspective, based on published literature and expert knowledge. The results from this assessment provide an understanding of the contributions of seagrass ecosystems to people's quality of life in each of the PICTs and will assist in future NCP assessments to inform effective policy and management strategies for seagrass ecosystem conservation.

2. Methods

To examine the contributions from seagrass ecosystems to peoples' quality of life (i.e. SCPs) across the Pacific Islands, we grouped the countries and territories according to both their geographic region and main ethnic/cultural origins; Melanesia, Micronesia, Polynesia. Melanesia (5,500,000 km^2) is in the southwest Pacific, Polynesia (13,200,000 km^2) in the eastern Pacific and Micronesia (8,800,000 km^2) in the central - northwest Pacific (Fig. 1). The PICTs have a variety of high islands and low atolls, each with a range of marine environments, some of which are suitable for seagrass colonisation and growth. The regions have rich geological histories, are exposed to frequent extreme weather events, and include a range of climates and complex oceanographic processes.

We examined the natural goods and contributions that may be perceived as benefits or detriments (depending on the cultural, socioeconomic temporal, or spatial context) to people's quality of life, directly or indirectly, contributed by seagrass ecosystems (i.e. SCPs) across the PICTs by applying a universally applicable set of categories of flows from nature to people, analytical in purpose. First, we divided the SCPs into regulating, material and non-material. Next, we followed the standardised framework established by de Groot et al. (2002) and Nordlund et al. (2016), and modified according to Díaz et al. (2018), to assess whether the SCPs varied depending on the seagrass species and human populations (including cultural and ethnic identity) from the 32 globally identified SCPs (Table 1). To identify the presence (including perceived) of each SCP in each of the PICTs, we searched the peer-reviewed and gray literature (Collins et al., 2015) and, due to the novel aspect of the topic, we implemented an expert-elicitation approach (Caley et al., 2014).

Literature sources were gathered using the search browsers GoogleScholar and Google in April 2020 and then again in August 2020, by combining keywords related to variations of the name "seagrass" (e.g. sea grass, turtlegrass, tapeweed, paddleweed, marine angiosperm and phanérogame), the respective seagrass genera, species, and local names (if known), with variants of each of the SCPs listed in Table 1 (i.e. ecosystem service, fishing, nursery, gleaning, dugong, turtle, food, medicine, fertilizer, livelihood, nutrition, wellbeing, spiritual, culture, tourism, education, tradition, Indigenous Knowledge and custom/kustom), and names of each Pacific Island country and territory.

Expert elicitation followed a standardised five step approach by; deciding how information will be used, determining what to elicit, designing the process, performing the elicitation, and translating the information into quantitative statements (Martin et al., 2012).

Table 1
List and description/example of recognised ecosystem contributions by seagrass globally and recommended reporting category for Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessments according to the generalizing perspective (Table S1). Description includes goods, functions, processes, components, or life support systems. List modified from de Groot et al. (2002), Nakaoka et al. (2014), Ramesh et al. (2019), Newmaster et al. (2011), Nordlund et al. (2016) and Díaz et al. (2018).

Seagrass ecosystem contribution (SCP)	IPBES category	Description
Material		
Bioindicator	1	seagrass assessed as an indicator of water quality/ecosystem health
Compost fertilizer	8, 15	wrack collected and placed on land crops
Dietary supplement *(for humans)*	12, 15	e.g. *Enhalus* fruits eaten by fishermen as snack
Genetic resources	14	Includes the genes and genetic information used for animal and plant breeding *(including restoration)*
Seagrasses as food for detrital and filter feeders	12	food for sea cucumbers, crabs, etc.
Seagrasses as food for herbivores	12, 15, 17	food for fish, dugong, sea turtle, urchins, etc.
Source of human food from seagrass gleaning	12, 17	e.g. sea cucumbers and urchins collected from meadows during low tide
Mariculture *(as a substrate)*	1, 13	e.g. meadows used for sea cucumber ranching
Nursery	1, 17	e.g. juvenile habitat for reef fishery
Ornamental resources	13, 17	Animal and plant products such as skins, shells. and flowers, are used as ornaments, and whole plants are used for landscaping and ornaments
Pharmaceuticals *(incl traditional medicines)*	14, 17	Parts or extracts of plants used for treatment of, but not limited to, heart, general health, mental disorder, dermatological, infection or gastrointestinal
Fibre/raw materials (e.g. *weaving, roof thatch)*	13, 17	e.g. used for weaving or roof thatch
Source of human food from seagrass fishery *(net, trap, spear)*	12, 13, 17	e.g. rabbitfish harvested using nets/traps for local consumption or export
Stock feed supplement	12	e.g. plants harvested or wrack collected from shore used as livestock fodder
Trophic subsidy	1	e.g. feeding area for coral reef fish at night
Regulating		
Carbon sequestration *(climate regulation)*	4	long-term removal or capture of carbon dioxide to slow or reverse atmospheric CO2 pollution and to mitigate or reverse global warming
Regulates ocean acidification	5	increases pH, resulting in 18% higher calcification of reefs
Sediment stabilization *(erosion regulation)*	8	Vegetative cover plays an important role in soil retention and the prevention of landslides
Water purification	7	Regulates land based pollution (act as nutrient, sediment, chemical, filter/buffer)
Disease regulation/ mitigation	7, 10	reduces 50% of bacteria harmful to humans and corals
Natural hazard regulation/ Coastal protection	9	seagrass presence can reduce the damage caused by storms and waves by dampening
Non-material		
Aesthetic significance	16, 17	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks. Scenic drives. and the selection of housing locations
Bequest benefit	17	satisfaction of preserving seagrass for enjoyment by future generations
Cultural artifacts	15, 17	

(continued on next page)

Table 1 (*continued*)

Seagrass ecosystem contribution (SCP)	IPBES category	Description
		protector of shipwrecks, archaeological artifacts or archaeological / cultural significant sites (excludes recent human past e.g. World War II plane and ship wrecks afforded protection by seagrass meadows)
Education	15, 17	Ecosystems and their components and processes provide the basis for both formal and informal education in many societies
Inspirational	15	Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture, and advertising
Knowledge systems	15, 17	Ecosystems influence the types of knowledge systems developed by different cultures
Recreation and ecotourism	16, 17	People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area. Provide habitat for wildlife viewing opportunities and other recreational opportunities such as swimming through clearer, cleaner water and stable beaches, as well as recreational fishing
Scientific research	15	academic pure and applied
Sense of place	17	Many people value the sense of place that is associated with recognised features of their environment, including aspects of the ecosystem
Social relations	17	Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example. Differ in many respects in their social relations from nomadic herding. or agricultural societies
Spiritual & religious	17	Many religions attach spiritual and religious values to ecosystem or their components. Sacred elements of the biota and living systems; worship of biota; kindness and gratitude towards biota

Responses were used to identify known or perceived occurrence of SCPs across the PICTs. Experts were asked to confirm the occurrence of each SCP listed in Table 1 in countries or territories where they had expert knowledge, and provide evidence (e.g. photographs, peer-reviewed or gray literature). We defined an expert as "anyone with relevant and extensive or in-depth experience in relation to a topic of interest" (Krueger et al., 2012) and directly targeted experts with in-depth understanding of seagrass or coastal ecosystems. Co-author's nominated PICTs from which they elicited responses, based on their geographical working experience (i.e. where their expertise was strongest). Responses were solicited from professional collaborators/colleagues and networks (e.g. Seagrass-Watch Global Seagrass Observing Network). This process was necessary as few experts across the Pacific Islands have in-depth expertise across all SCPs. This process also provided opportunities for engagement with a wide diversity of knowledge systems (including indigenous/traditional ecological knowledge) and stakeholders (e.g. indigenous people, businesses, local and remote communities, fishers). Elicited responses from all PICTs were collated into an excel file. The information collected identified each SCP within each PICT as: present (contribution perceived to be present), unknown (contribution might be present), or not present (contribution known to be absent or could not be classified even in the "unknown" category) and determined the frequency of SCP occurrence across all PICTs. For our assessment, we also confined our non-material SCP "cultural artifacts" to only include Indigenous and excluded non-Indigenous, e.g. European artifacts, post colonisation.

3. Results and discussion

Approximately 71% of the PICTs population (excluding PNG) live within 1 km of the coast (Andrew et al., 2019), indicating that the marine environment likely plays an important role in the lives of Pacific Islanders. Throughout the PICTs, seagrass ecosystems contribute a wide variety of goods and benefits that support human well-being and livelihoods. Of the 32 SCPs reported for seagrass globally, 30 were perceived as present in the PICTs (Tables 2, S2). The number of SCPs from seagrass ecosystems was higher in Melanesia, than Micronesia and Polynesia, respectively (Fig. 2). Also, a greater proportion of countries and territories within Melanesia perceived more SCPs, than any other region (Fig. 2). In many PICTs, the presence of some contributions were unknown, generally indicating the contribution is yet to be realised within marine conservation legislation and policy. Our analysis revealed an unbalance in the type of SCPs perceived across the PICTs (Fig. 2). The greatest number of SCPs were identified as Material, followed by Non-material and Regulating, respectively (Fig. 2).

3.1. Material seagrass contributions to people (Material SCPs)

The goods and benefits people obtain from seagrass ecosystems (Material SCPs) range from providing juvenile habitat for fisheries to ornamental animal collection. The material contribution with the highest frequency of perceived occurrence in the PICTs was food for herbivores (e.g. fish, dugong and turtle), followed by nursery habitat for fish and invertebrates, intertidal gleaning for food (mostly invertebrates) and food for detritivores (Fig. 2); all of which contribute directly or indirectly to food security and livelihoods for Pacific Islanders. The provision of food security and livelihoods from seagrass, particularly through subsistence fisheries, is widespread and critical, appearing to have occurred since early settlement of the region. For example, stable isotope signatures in skeletal remains from a Lapita burial ground (ca. 2800–2350 BP) on Watom Island (northeast New Britain, PNG) indicate the primary nitrogen source was seagrass, suggesting a protein diet of fish and sea turtles harvested from nearshore seagrass habitats (Kinaston et al., 2015). The reliance on seagrass underpinning fisheries is high across the PICTs, with all PICTs where seagrasses occur reporting seagrass to provide subsistence for local communities, support for rural livelihoods and provision of significant revenue for governments.

3.1.1. Seagrass as fishing grounds

Fishing is an integral part of Pacific Islander culture, and seagrass ecosystems represent a traditional way of life and identity for fishers and communities, as they are directly associated with food security, livelihoods and spiritual fulfilment. The significance of the seagrass fishery appears poorly documented and quantified throughout the Pacific (Nordlund et al., 2018), as the fishery is not independently acknowledged; often being incorporated with nearshore reef flat, sand, mudflat or mangrove fisheries (Waycott et al., 2011). Nevertheless, closer examination reveals the fishery is widespread (Table 1, Fig. 3), as most sheltered nearshore areas have some seagrass present. Available evidence indicates the seagrass habitat is explicitly targeted as a fishing ground due to its high fish and invertebrate abundance as well as it's accessibility (Nordlund et al., 2018). Seagrass ecosystems provide nursery areas for juveniles of fish (Fig. 4a) and prawns/shrimps, feeding grounds for coral reef fish at night, and habitat/shelter for invertebrates gleaned at low tide throughout the wider Indo-Pacific region. However, only limited quantification of this has been undertaken at the local level in the PICTs. Approximately 40% of fish species reported from seagrass meadows in the PICTs use the habitat only as juveniles, and 16% only when adults (Table S3). The seagrass fishery targets in particular,

Table 2
Natures Contributions to People provided by seagrass ecosystems (SCPs) in the PICTs. Species within each PICT summed according to their life history traits and strategies, as broadly defined by Kilminster et al. (2015). P and Green = present, Gray = unknown, White = absent. For sources, see Table S2.

		MELANESIA					MICRONESIA							POLYNESIA									
	Seagrass species and SCPs	Fiji	New Caledonia	Papua New Guinea	Solomon Islands	Vanuatu	F.S. Micronesia	Guam	Kiribati	Marshall Islands	Nauru	Nth Mariana Islands	Palau	American Samoa	Cook Islands	French Polynesia	Niue	Pitcairn Islands	Samoa	Tokelau	Tonga	Tuvalu	Wallis et Futuna
	Number of Colonising species	3	5	4	3	5	2	1	1	1	0	1	2	1	0	2	0	0	2	0	2	0	1
	Number of Opportunistic species	3	5	6	4	5	4	1	0	1	0	1	5	1	0	0	0	0	2	1	3	0	3
	Number of Persistent species	0	2	3	3	3	3	1	2	2	0	1	3	0	0	0	0	0	0	0	0	0	0
	Presence of local name for seagrass (Table 3)	P			P	P	P		P	P			P	P					P				
Material	Nursery	P	P	P	P	P	P	P	P	P		P	P	P					P		P		
Material	Trophic subsidy	P	P	P	P	P	P	P	P	P		P	P										
Material	Dietary supplement (for humans)				P				P														
Material	Source of human food from seagrass fishery	P	P	P	P	P			P				P			P					P		P
Material	Source of human food from seagrass gleaning	P	P	P	P	P	P	P	P	P		P	P						P		P		P
Material	Seagrasses as food for herbivores	P	P	P	P	P	P	P	P	P		P	P	P		P			P		P		P
Material	Seagrasses as food for detrital and filter feeders	P	P	P	P	P	P	P	P	P		P	P						P		P		P
Material	Fibre/raw materials (e.g. weaving, roof thatch)	P			P		P		P														
Material	Compost fertilizer	P			P																		
Material	Pharmaceuticals (incl traditional medicines)	P			P		P																
Material	Mariculture (as a substrate)	P		P	P				P				P										
Material	Bioindicator	P			P							P		P							P		
Material	Stock feed supplement																						
Material	Genetic resources																						
Material	Ornamental resources	P	P	P	P	P															P		P
Non-material	Bequest benefit	P																					
Non-material	Spiritual & religious	P			P				P	P						P							
Non-material	Knowledge systems	P			P																		
Non-material	Education	P		P	P																		
Non-material	Inspirational												P										
Non-material	Aesthetic significance						P	P		P		P											
Non-material	Social relations	P			P																		
Non-material	Sense of place	P			P																		
Non-material	Cultural artifacts						P																
Non-material	Recreation and ecotourism	P			P	P						P									P		
Non-material	Scientific research	P	P	P	P	P	P	P		P		P	P								P		
Regulating	Carbon sequestration (climate regulation)	P	P	P	P	P	P	P		P		P											
Regulating	Mitigates ocean acidification (benefits coral reefs)	P	P	P	P	P						P	P										
Regulating	Sediment stabilization (erosion regulation)	P	P	P	P	P	P	P		P		P		P							P		
Regulating	Water purification	P	P	P	P																		
Regulating	Disease regulation/mitigation	P	P	P	P																		
Regulating	Natural hazard regulation/Coastal protection	P	P	P	P	P	P	P		P		P											

rabbitfishes (Siganidae), emperor (Lethrinidae), silver biddies (*Gerres* spp.), goatfish (Mullidae), mullet (Mugilidae) and other reef associated species such as parrot fish (Scaridae), surgeonfishes (Acanthuridae), jacks (Carangidae), and snappers (Lutjanidae); as well as an extensive variety of invertebrates such as species of sea cucumber, bivalves, gastropods and urchins (Carleton et al., 2013; Jimenez et al., 2012; Nordlund et al., 2018; Sambrook et al., 2019; Waycott et al., 2011) (see also Table S3).

Pacific Islanders use a wide variety of methods (e.g. nets, spears, traps, poisons and stupefacients) to collect a wide range of marine resources from seagrass ecosystems (Fig. 3). Nets used in the seagrass fishery are mostly monofilament, but those from natural fibres are still sometimes used, and vary in volume and mesh size. Beach seine and gillnet fishing is used predominantly by artisanal fishers for commerce (Fig. 3a,b), whereas the use of wading, scoop and drag nets is generally for subsistence fishing in the inshore seagrass meadows. Nets are more widely used by men, however small drag and scoop nets are used mostly by women (Veitayaki, 1995). Spears of various types are used from the surface or underwater (Fig. 3c). Traps can be woven baskets or walls (weirs and fences) built of either stones or sticks (e.g. mangrove) in shallow intertidal areas (Fig. 3d). Baited wire mesh or gill net traps (dilly pots) are placed in intertidal meadows bordering mangroves across Melanesia and Micronesia to catch mud crab (*Scylla serrata*) (Dalzell et al., 1996; Léopold et al., 2014). The fence or weir is either J or U shaped, with the bend towards the sea and is used throughout Melanesia, Micronesia and parts of Polynesia (e.g. Tonga, Samoa). These fish fences, similar to those used in other parts of the tropics (see Exton et al., 2019), are submerged at high tide and during outgoing tides the fish are channelled along the walls and funnelled into collection pens. Fish poisons and stupefacients are also used on the reefs and in shallow areas. For example, in Fiji, the common sea cucumber ("*loliloli*", *Holothuria atra*) found within reef flat seagrass meadows, is rubbed in the sand to emit a red and purplish liquid which contains a nerve toxin capable of poisoning or stupefying fish and chasing octopuses out of their lairs (Veitayaki, 1995). Burrowing mantis shrimps (Stomatopoda) that live in seagrass meadows are also caught for subsistence using snare traps in the Solomon Islands, or simple baited entanglement traps (e.g. nylon stocking) in PNG (Dalzell et al., 1996).

Gleaning, or gathering by hand, is probably the oldest and most widely used fishing method in shallow inshore meadows and is conducted at any time of the day or night corresponding to low tide. Gleaning is mostly conducted by women, who search pools and skim the meadows during low tide for invertebrates using their bare hands, sticks, knives, or sharp pointed iron rods (Fay et al., 2007; Friedman et al., 2009; Jimenez et al., 2015; Veitayaki, 1995). In Fiji, gleaning ("*vakacakau*") remains popular today (Fig. 3e) and the catch often consists of bivalves (e.g. *Anadara* spp.), gastropods (e.g. *Lambis lambis*), sea cucumber (*Holothuria scabra*), sea urchin (*Tripneustes gratilla*) and sea hare

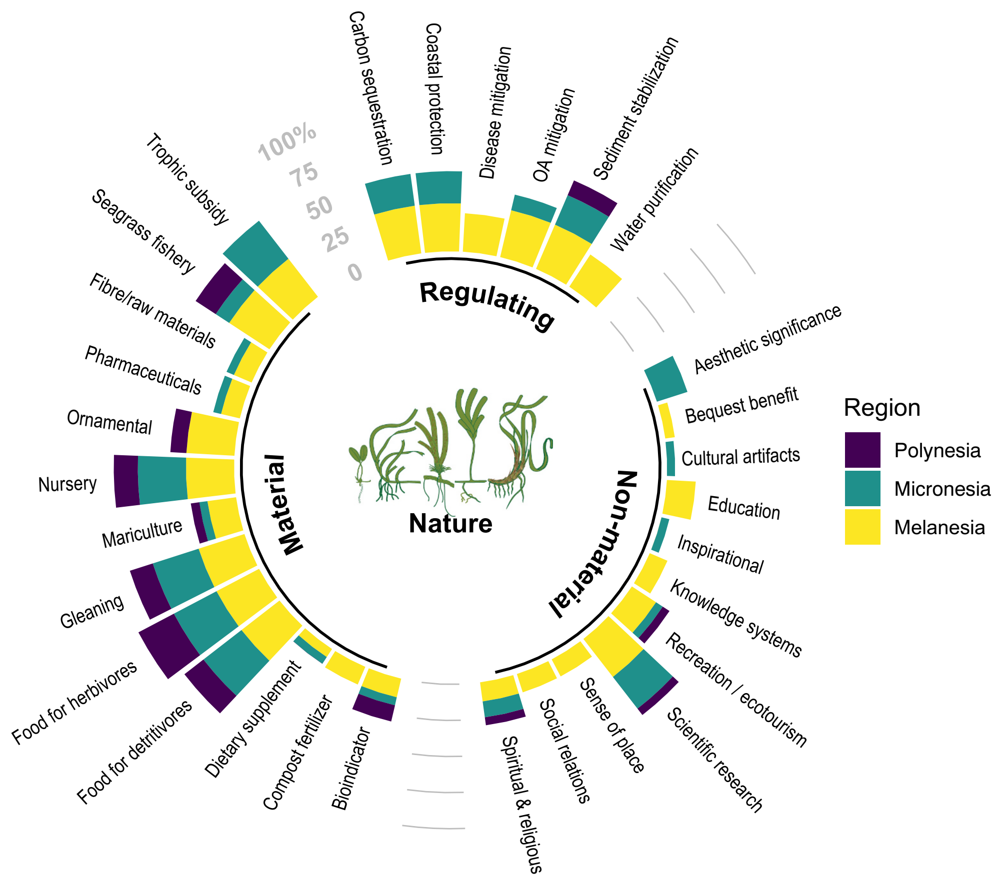

Fig. 2. Seagrass ecosystem contributions to people (SCPs) across the Pacific Islands. Frequency of known occurrence (percentage of countries and territories) of SCPs within each region (equally scaled), where: 100% = contribution present in every PICT; and Regional = 33% when contribution present in every country or territory of a region.

(*Dolabella auricularia*) (Fig. 3f). The collecting bag ("*noke*") was traditionally made from woven reeds (Quinn and Kanalagi, 1998). *Anadara* spp. prefers intertidal seagrass habitats with muddy sediments and remains an important source of dietary protein across Melanesia and Micronesia (Fig. 3g); contributing significantly to household incomes, particularly in Kiribati (Fay et al., 2007).

Similarly, the seagrass detrital feeding sea cucumbers, which support a significant fishery throughout Melanesia and parts of Micronesia (FSM, Kiribati and Palau) and Polynesia (Samoa and Tonga), are critically dependent on shallow seagrass meadows; which serve predominantly as juvenile nursery habitat for target species (e.g. *Holothuria fuscogilva, Holothuria scabra, Stichopus horrens* and *Holothuria atra*) (Jimmy et al., 2012) (Fig. 3h). Seagrass areas have also been used for mariculture in Melanesia and Micronesia (Fig. 3), such as sea cucumber ranching/grow out and restocking in Fiji, Kiribati, New Caledonia, Palau, and Papua New Guinea (Jimmy et al., 2012).

3.1.2. Seagrass as food for herbivores

Seagrass provides food for herbivores other than fish and invertebrates, such as green sea turtles (*Chelonia mydas*) and dugong (*Dugong dugon*); which are seagrass community specialists, an important source of protein, and of very high cultural significance for Pacific Islanders. Green sea turtles occur in all PICTs except Nauru, and are listed as endangered by the IUCN due to historical exploitation for their meat, oil (rendered fat), eggs, bones (as tools), skins (leather) and shell (combs, bracelets and fish lures). As a consequence, green sea turtles are now protected across the PICTs by a number of International agreements (e.g. the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)) and individual National legislative processes and regulations (e.g. Fisheries and Wildlife Protection Acts) (Maison et al., 2010). Many communities continue to utilise green sea turtles for protein on a subsistence level (e.g. New Caledonia (Sabinot and Bernard, 2016)). Long-term monitoring since 2002, has shown increased green sea turtle populations in CNMI, Guam and American Samoa; indicating regulations may be assisting the recovery of populations (Becker et al., 2019). However, the status of populations throughout the remaining PICTs is not well known (Work et al., 2020).

Dugongs in the PICTs are restricted to Melanesia and parts of Micronesia where extensive seagrass meadows occur (Fig. 4b). Palau's dugong population is considered to be the most isolated in the world and Vanuatu is generally accepted as the eastern limit of the dugong's range, although the occasional dugong has been reported from Fiji (Hill-Lewenilovo et al., 2019). Across the Pacific Islands, dugongs are traditionally harvested for their meat, oil and hides (Chambers et al., 1989; Hudson, 1977; Marsh et al., 2011). Dugong meat provides an important source of protein for local communities, and in PNG, for example, the hide was traditionally used for drums and decorations, while teeth and bones were made into hooks in Morobe Province, or betel nut crushers and necklaces in the Milne Bay region (Hudson, 1977). Although considered sustainable in the past, subsistence harvesting of dugongs in the Pacific, in combination with increasing human populations and the introduction of new harvesting technologies, has severely impacted the species. As a consequence of globally declining populations, the dugong is listed as Vulnerable on the IUCN Red List of Threatened Species, and is protected by legislation in Palau, New Caledonia, Papua New Guinea, Solomon Islands and Vanuatu. Nevertheless, opportunistic subsistence take of dugongs and the consumption of dugong meat during occasions of cultural significance, continue at a low level across the region (DSCP,

Fig. 3. Seagrass meadows support important PICT fisheries: **A.** gill net fishing, *Enhalus acoroides* meadow, San Jorge Island, Solomon Islands; **B.** gill net fishing, *Syringodium isoetifolium* meadow, Nukubuco, Fiji; **C.** simple spear fishing in mixed *Cymodocea rotundata* /*Halodule uninervis* meadow, Huleo Island, Solomon Islands; **D.** traditional Polynesian stone fishing trap, Huahine, French Polynesia (C. Roelfsema); **E.** gleaning the intertidal *Halodule* meadow on the shores of Nasese, Lacuala Bay, Fiji; **F.** sea hare (*Dolabella auricularia*) in *Halodule uninervis* meadow, Nukubuco, Fiji; **G.** kaikoso (*Anadara* spp.) gleaned from seagrass meadows, Suva market, Fiji; **H.** sandfish (*Holothuria scabra*) gleaned from seagrass meadows, Pohnpei, FSM.

2018). The dugong population throughout the PICTs is not well known, but is estimated to be in the thousands (Marsh et al., 2011). The population in New Caledonia appears relatively stable, with the most recent estimate (in 2012) between 649 (±195) and 1227 (±296) individuals (Cleguer et al., 2017). There are a number of anecdotal reports that populations are unchanged or increasing in the eastern provinces of Papua New Guinea (Bass, 2009), and although only 20 or so animals were reported in Vanuatu in 1987, the reports indicated numbers were either unchanged or increasing (Chambers et al., 1989), and the population today is thought to be significantly larger (DSCP, 2018). Similarly, in Palau, early estimates of 50 to 100 animals are likely an underestimate of the actual population (Colin and Etpison, 2013; Jaiteh et al., 2020; Marsh et al., 2011).

3.1.3. Ornamental products

Seagrass ecosystems directly and indirectly provide ornamental resources including products used as curios/ornaments, handicraft production and display aquaria, from plants and animals' dependent on seagrasses for all or part of their life. For example, mollusc shells collected from nearshore intertidal seagrass meadows have multiple roles, including ornamentation, wealth, demonstration of status, and as ritual paraphernalia, and various symbolic associations within a society (Trubitt, 2003). Shell money, made from gastropods or bivalves which inhabit nearshore seagrass meadows, is used traditionally in Melanesia (e.g. PNG, Solomon Is, New Caledonia and northern Vanuatu) in various forms as the currency of choice in bride price (dowry) ceremonies, a form of compensation used to settle disputes, as jewellery and to trade for various other goods (Lewis, 1929). For example, shells of the gastropod *Chrysostoma paradoxum* used to make traditional orange shell-money "*mis*" (Fig. 4c), are collected from seagrass meadows with mud and mixed sand sediments on the north-west side of New Hanover and the Tigak Islands of New Ireland Province, Papua New Guinea (Simard et al., 2019). Most of the money has the form of small disks or beads arranged in strings (strips), the value depending on the kind of disk and the length of the strip. Shell money ("*tambu*") is also the currency of the Tolai people of the Duke of York Islands and Gazelle Peninsula (East

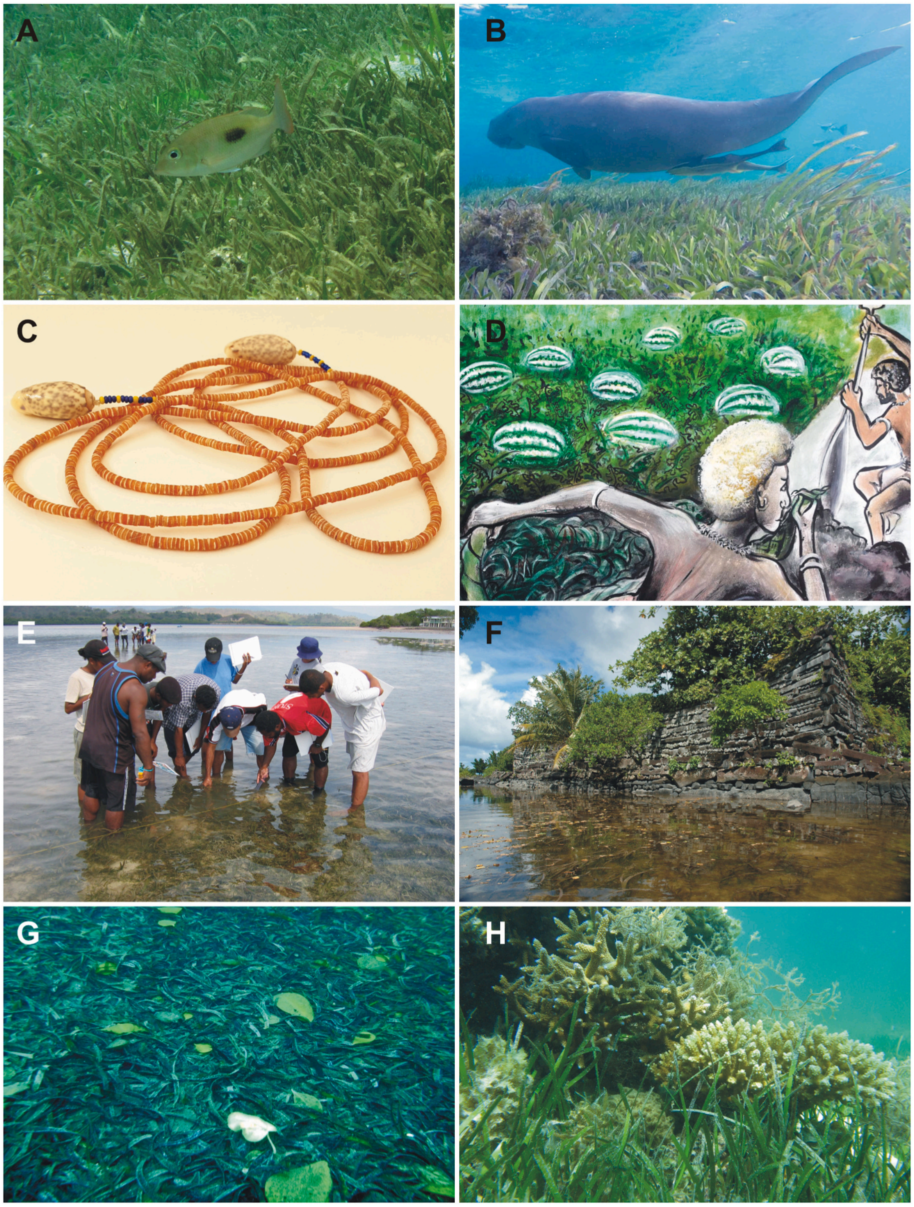

Fig. 4. Seagrass ecosystems in the PICTs provide important contributions to people: **A.** juvenile habitat for reef fishery, e.g. *Lethrinus karak* in *Cymodocea/Halodule* meadow, Tetapare Island, Solomon Islands; **B.** food for herbivores, e.g. dugong, Palau; **C.** Ornamental resources, e.g. shell money from Kavieng, Papua New Guinea; **D.** compost fertilizer, e.g. traditional story of farmers using seagrass wrack to fertilise watermelons, Lau, North Malaita, Solomon Is. (WorldFish, painting by John Limaito'o); **E.** education, basis for both formal and informal, e.g. students from University of Papua New Guinea, Motupore Island, PNG; **F.** protection of cultural artifacts and culturally significant sites, e.g. Nan Madol, Pohnpei, FSM; **G.** food for detrital feeders and carbon sequestration, e.g. thick layer of decomposing *Enhalus acoroides* and *Thalassia hemprichii* leaves, accumulated at 30 m depth in a deep cleft, Nglit Inlet, Palau; **H.** regulates ocean acidification to increase calcification of reefs, e.g. Levuka reef, Fiji.

New Britain, PNG) (Szabó, 2018). Tambu is made from the parietal and lip shield of *Nassarius fraudulentus* (*aka Nassa callosa*) shells, which are harvested from the coastal seagrass meadows of PNG (New Britain, New Ireland) and the Solomon Islands (Lewis, 1929; Parkinson, 2010). There are other types of shell money ("*vula*" and"*diwarra*"), currency of the Kaliai people of north-west New Britain, which are made from shards of bivalve shells (Lewis, 1929; Parkinson, 2010). In Auki, Malaita (Solomon Islands), shell money strips are made from a selection of four different coloured bivalves, including the white cockle (*Anadara granosa*), which inhabits the muddy sediments of nearby seagrass meadows of Langa Langa lagoon (Fidali-Hickie and Whippy-Morris, 2005).

Other ornamental products from seagrass meadows include invertebrates for commercial and hobby aquaria and dried decorations, e.g. the common blue sea star (*Linckia laevigata*) harvested on reefal seagrass meadows in Tonga (FMPS, 2008). Ornamental products from seagrass ecosystems are not restricted to invertebrates, as a number of vertebrate fauna are also valued in the ornamental trade, including green sea turtle (skin and shell) and dried syngnathids (seahorses, pipefish). Although International trade in green sea turtle leather (made from the skin) and shell (carapace) is prohibited across most of the PICTs by CITES, concerns remain of customary use and a continuing illegal "black market" trade. Locally, green sea turtle shells are used for traditional decorative and ceremonial purposes. Syngnathids (seahorses, pipefish), of which some species rely on seagrass habitats, are exploited globally for the aquarium trade, as curios, and for their properties in Chinese traditional medicine (Martin-Smith and Vincent, 2011). Within the PICTs, the only reports of syngnathids being traded comes from Fiji, where a few dried seahorses were noted for sale in curio shops in 1994 (Vincent, 1996), and from Europe in 1998 where three wild-caught *Hippocampus* spp. were exported from the Solomon Islands to Germany for commercial purposes (Martin-Smith and Vincent, 2011). Illegal export and sale of syngnathids is common in other parts of the Indo-Pacific region but it is not clear whether such activity happens in the PICTs. In 2004, all species of seahorse (*Hippocampus* spp.) were listed under Appendix II of CITES, restricting trade to ensure it is not detrimental to wild populations, and that they are legally sourced.

3.1.4. Direct consumption and use of seagrass plant material

Nearly 40% of the Material SCPs from PICTs seagrass ecosystems are provided directly from the seagrass plant (Fig. 2), in a similar manner to how others have traditionally exploited seagrass seeds and fruits around the World (Felger and Moser, 1973; Nessa et al., 2020; Ratnawati et al., 2019). Although uncommon, seagrass directly provides a dietary supplement for humans in two PICTs (Fig. 2). For example, it has been reported from Roviana (Solomon Islands) that in the past, rhizomes of *Enhalus acoroides* were eaten raw (Lauer and Aswani, 2010). Also, at Naro, northern Guadalcanal (Solomon Islands), fruits of *Enhalus acoroides* were collected, and grilled on hot stones as a snack for children (Iyengar, 2018). In Kiribati, during times of drought when not only farmed vegetables but all kinds of fish were scarce, the islanders would eat the stalks and foliage of *Thalassia hemprichii* (Grimble, 1933).

Seagrass has been used globally throughout history as a fibre/raw material (Wyllie-Echeverria et al., 1999; Wyllie-Echeverria and Cox, 2000) and is still used in a variety of products in Melanesia and Micronesia. For example, in the Western Province of the Solomon Islands, Roviana villagers use dried *Enhalus acoroides* leaves as fibre for stuffing pillows and assembling fishing lures (Lauer and Aswani, 2010). Today in Roviana, the leaves continue to be used for shell necklaces and to catch banded mantis shrimp (*Lysiosquillina maculata*) known as "*hahaka*". In Micronesia, prior to World War II, fishers on Yap used the vascular fibres of *E. acoroides* leaves to construct fishing nets that would last generations (Falanruw, 1992).

Due to its high nitrogen and phosphorus content, seagrass is used as an agri-fertilizer in several Pacific countries. For example, *Syringodium isoetifolium* is harvested by Dakuni villagers in Beqa (Fiji) and added to the base of tomato seedlings, as it is reported to produce bigger, disease and pest-free plants with more fruits (N'Yeurt et al., 2013; N'Yeurt and Iese, 2015). In Lau Lagoon, North Mailita (Solomon Islands), watermelons are an important agricultural commodity and farmers collect seagrass wrack on the beach, and use it to improve soil fertility of their gardens; not only producing bigger, but the sweetest melons in the country (Fig. 4d) (WorldFish, 2017).

Seagrass is used as pharmaceutical/traditional medicines in Melanesia and Micronesia. *Enhalus acoroides* in Yap, Chuuk and Pohnpei, is reported to be used as "protective medicine" for women who are going into the ocean (Merlin, 2002). In Naro (northern Guadalcanal, Solomon Islands), leaves (possibly *E. acoroides*) are used as a traditional medication to relieve the pain from a fish sting (Iyengar, 2018). These reports are similar to those from east Africa where the roots of *E. acoroides* are used by fishermen as a remedy against Scorpaenidae and Siganidae stings (de la Torre-Castro and Ronnback, 2004). Acceptance of the medicinal uses of seagrass has increased in recent years, with research reporting cytotoxic and anti-inflammatory properties of extracts from many species (Abdelhameed et al., 2018; Kim et al., 2021; Subhashini et al., 2013).

3.1.5. Other Material benefits of seagrass

There is growing acceptance globally of the role that seagrasses can play as an indicator of the health of the coastal and marine environment. Examples include their use in the EU Water Framework Directive and the Great Barrier Reef Marine Park Marine Monitoring Program (Duffy et al., 2019). Although this use is broadly acknowledged in the PICTs, we find Tonga and CNMI were the only countries or territories to integrate seagrass as part of their water quality assessment and monitoring programs (Fakatava et al., 2000; Yuknavage et al., 2018).

Only two seagrass Material SCPs were not recognised in any of the PICTs: Stock feed supplement and Genetic resources. Although livestock (e.g. pigs) are known to feed in intertidal meadows during low tides in several PICTs, this was not considered as stock feed as defined in Table S1; "the harvesting of live plants or the collection of wrack from the shore to be fed to livestock". The provision of Genetic resources was also not recognised, however, with interests in broodstock collections (e.g. sea cucumber mariculture) and seagrass restoration activities, the lack of genetic assessments may be overcome in the near future (McKenzie and Yoshida, 2020).

3.2. Non-material SCPs

3.2.1. Language and culture

Seagrass meadows are perceived to provide 11 different Non-material SCPs across the PICTs, with the greatest proportion in Melanesia, followed by Micronesia and Polynesia respectively (Fig. 2). An indicator of cultural diversity is language, and if seagrasses have a specific name in a local language (i.e. people know what they are), then they can be assumed to have some perceived benefit for the contributions they provide (de los Santos et al., 2020). Throughout the PICTs, numerous languages denote the distinct benefit of seagrass as a biological entity (Tables 2 and 3). For example, across the Solomon Islands, seagrasses is known by around 14 different names (Table 3), as seagrass meadows are considered one of the most valuable habitats for Solomon Islanders (Iyengar, 2018; WorldFish, 2018). Some local names relate to the ecology of certain species in providing important contributions, as well as to reproductive ecology, e.g. "the month when the seagrass flowers" (Iyengar, 2018; WorldFish, 2018). On Malekula Island (Vanuatu) *Thalassia hemprichii* is called "*nulas nga murol*" (short seagrass) or "*nanen nga nevu*" (food of the turtle), *Enhalus acoroides* is called "*nulas nga miprev*" (long seagrass), and *Halophila* spp. is called "*nanen se buris*" (food of the dugong) (Hickey, 2007). In other PICTs, the name for seagrass can apply to all species without distinction. In Marshallese, seagrass is called "*wūjooj-in-lojet*" or "*ujoij-in-lojet*" which translates to "grass of the ocean" (Vander Velde, 2003).

3.2.2. The spiritual significance of seagrass

Across parts of Melanesia and Micronesia, seagrass ecosystems are shown respect by many coastal Indigenous peoples and considered sacred. For example, in Naro village (Solomon Islands) seagrass meadows are described as fish gardens or taboo areas for replenishment of sea resources. Images of seagrass ecosystems also have significance, and the forked shape of *Enhalus acoroides* flowers is often used as an inlay design adorning the beams of *bai*, the traditional men's houses of Palau (Krämer, 1917). Traditional needs to safeguard seagrass ecosystems also enhances the perception of threats to healthy seagrass meadows and encourages support for both formal and informal education campaigns and curricula (Fig. 4e) (Iyengar, 2018).

Several Melanesian cultures have a spiritual connection/dimension to seagrass ecosystems, from the cultural use of products (e.g. traditional use of "shell money"), to myths and legends. For example, in Roviana (Solomon Islands), where local communities rely heavily on seagrass for their daily subsistence needs, fishers twist the fibres from three *Enhalus acoroides* leaves together and shout "*Kuli pa Kovi*!" (seagrass of Kaovi!) to call the seagrass spirits from Kaovi Island (the seagrass spirit home) to improve their catch (Lauer and Aswani, 2010). Seagrass plays a greater spiritual role in Roviana, where tying *Enhalus* fibre knots is thought to be useful as an aphrodisiac spell to attract a member of the opposite sex (*vinaroro*) as well as to ensure that a newborn child will be gifted in some special craft or art (*matazonga*) (Lauer and Aswani, 2010). In each case, specific tying procedures and incantations are required in order to produce the desired effect (Lauer and Aswani, 2010).

Many cultures attach spiritual and religious significance to not only seagrass plants and ecosystems, but also their associated species. This includes sacred elements of the biota, worship of biota, or kindness and gratitude towards biota. Charismatic species which rely on seagrasses, such as green sea turtles and dugong, have both a Material and Non-material significance. Throughout its range, the dugong plays a central role in traditional ceremony and lore. In some societies, the dugong is considered to be an important totem (due to its large size and strength), and features prominently in enduring stories and legends (e.g. Solomon Islands). The custom or source stories show attachment, relationships, uniqueness, priorities, and behaviours towards the dugong and seagrass in an informal yet tangible way. Custom stories are passed on and recounted with fervour through generations, reinforced through present-day experiences (Iyengar, 2018). Dugong bones and tusks can

Table 3
Local vernacular names for seagrass (if known) in each PICT. Text in parenthesis refers to name if other than generic.

PICT	Location	Local language	Source
MELANESIA			
Fiji	national	*veivutia* or *co ni waitui*	McKenzie and Yoshida, 2020
New Caledonia		unknown	
Papua New Guinea		unknown	
Solomon Islands	Roviana	*kuli*	Lauer and Aswani, 2010
		kulikuliana (seagrass meadows)	Lauer and Aswani, 2010
		kuli gele (Enhalus acoroides)	Lauer and Aswani, 2010
		kuli ngongoto (Thalassia hemprichii / Halophila ovalis)	Lauer and Aswani, 2010
	Lau	*afu'u*	WorldFish, 2018
	West/East Areáre	*araka*	WorldFish, 2018
	LangaLanga	*alaga*	WorldFish, 2018
	Maringe	*buburu thonga*	WorldFish, 2018
	Kia	*rumu*	WorldFish, 2018
	Marovo	*checheu Pa Idere*	WorldFish, 2018
	Russell Islands	*bamu*	WorldFish, 2018
	Gilbertese	*kokolie*	WorldFish, 2018
	Vanikoro	*kingnekobe*	WorldFish, 2018
	Utupua	*namaga*	WorldFish, 2018
	Duff Islands	*kalokalo*	WorldFish, 2018
	Reef Islands	*nga*	WorldFish, 2018
	Naro	*buburu ni tasi*	Iyengar, 2018
Vanuatu	national	*nulas*	Hickey, 2007
	Crab Bay	*nanen nga nevu (Thalassia hemprichii)*	Hickey, 2007
		nulas nga miprev (Enhalus acoroides)	Hickey, 2007
MICRONESIA			
Federated States of Micronesia	Pohnpei	*oaloahd*	Herrera et al., 2010
		olot, ohlot (Thalassia hemprichii)	Glassman, 1953
	Pingelap Atoll	*walat (Thalassia hemprichii)*	Glassman, 1953
	Mokil Atoll	*walap (Thalassia hemprichii)*	Glassman, 1953
	Kosrae	*kahp (Thalassia hemprichii)*	Glassman, 1953
	Chuuk	*mut (Thalassia hemprichii)*	Glassman, 1953
Guam		unknown	
Kiribati	national	*te keang*	Catala, 1957; Thaman, 1987
Marshall Islands	national	*wūjooj-in-lojet* or *ujoij-in-lojet*	Vander Velde, 2003
Nauru		unknown	
Northern Mariana Islands		unknown	
Palau	national	*char*	Krämer, 1917
	Tobi Island	*tsimorinom*	Sharon Patris, Pers. Comm.
POLYNESIA			
American Samoa	national	*limufoe (Halophila ovalis)*	Pratt, 1878; Skelton, 2003
		limuvao (Syringodium isoetifolium)	Pratt, 1878; Skelton, 2003
Cook Islands		NA	
French Polynesia		unknown	
Niue		NA	
Pitcairn Islands		NA	
Samoa	national	*limufoe (Halophila ovalis)*	Pratt, 1878
		limuvao (Syringodium isoetifolium)	Pratt, 1878
Tokelau		unknown	
Tonga		unknown	
Tuvalu		NA	
Wallis and Futuna		unknown	

have cultural significance, being used to symbolise prestige and high rank (e.g. vertebrae bracelets in Palau), and dugong meat is considered a prestige food ("meat of the leaders") often reserved for culturally important feasts, including weddings, funerals and custom ceremonies (e.g. Palau, PNG, Solomon Islands, Vanuatu, New Caledonia) (Chambers et al., 1989; Dupont, 2015; Hudson, 1977; Matthews, 2003; WorldFish, 2018). The activities associated with hunting dugongs and the preparation of the meat also have great significance and are an expression of long cultural traditions. Therefore, some cultures place traditional taboos against killing dugongs (e.g. Lau lagoon, Solomon Islands) (WorldFish, 2018).

Similarly, green sea turtles are an important element of Pacific traditions and cultures, featuring in many traditional myths, legends and songs: symbolising longevity, stamina, tranquillity and strength (Logan, 2006; Sabinot and Bernard, 2016). Throughout Polynesia, the green sea turtle's migratory nature (from seagrass feeding areas to nesting beaches) echoes the navigational spirit and paths of islander ancestors, and provides the foundation of legends and stories (Allen, 2007; Hopkins and Potter, 2010). Green sea turtles often feature in creation stories and are revered as sacred animals; intricately linked with culture and people's subsistence needs (Woodrom Rudrud, 2010). Traditionally, marine turtles were considered a sacred food item, often reserved only for men and those of noble birth (Allen, 2007; Woodrom Luna, 2013). In Fiji, green sea turtles are culturally significant as spiritual property and a prestige-food gift for feasts or traditional ceremonies associated with chiefs (Morgan, 2007). In Vanuatu, the meat is an important part of the Yam Festival (Guinea, 1993). As customary practices have eroded over time, both dugong and green sea turtles have become vulnerable or endangered due to excessive take (e.g. commercial gain and illegal hunting) and increased threats to their habitats (SPREP, 2011).

The benefit of seagrass protecting culturally significant artifacts or archaeological sites of cultural significance is relatively new (Krause-Jensen et al., 2019). The largest, oldest and one of the most significant archaeological sites in the PICTs is the UNESCO World Heritage Listed Nan Madol (Pohnpei, FSM); an administrative and mortuary site constructed of artificial islets that stretches over 83 ha of shallow fringing reef flat, surrounded by dense *Enhalus* and *Thalassia* meadows (Coles et al., 2005; McCoy et al., 2015) (Fig. 4f). Often referred to as the "Venice of the Pacific", the islets of Nan Madol, built from columnar basalt stones between 1180 CE and 1200 CE, are arranged in a formal layout with canals in between; the canals being occupied by dense seagrass (McCoy et al., 2016). The seagrass has afforded Nan Madol some protection by baffling waves and the through the accumulation of fine sediments over the years (Coles et al., 2005).

3.2.3. Seagrass for recreation and tourism

Seagrass ecosystems across the PICTs provide various recreational and tourism benefits. Although seagrass meadows may provide the opportunity to socialise while gleaning, or provide a field for playing rugby during low tide, seagrasses are not often recognised for providing a place people choose to spend their leisure time. In Saipan lagoon, seagrass is considered important to improve water clarity when proximal to dive sites (van Beukering et al., 2006), however, for the most part, seagrasses provide habitat for wildlife viewing opportunities. In Vanuatu, dugong viewing is a popular activity on Efate and Malekula, where tourists are able to swim (e.g. Pango Village (Port Vila) and Gaspard Bay (Lamap)), or SCUBA dive with dugongs (e.g. Port Vila) (Shaw, 2015). Due to the increased popularity of dugong encounters, the Vanuatu Environmental Science Society has developed guidelines and a code of conduct for tourism operators when interacting with dugongs and visiting seagrass areas (https://bit.ly/3o4zBAF).

In Tonga, the growing tourism industry has led to increased popularity for one of the region's most unique attractions - fishing pigs. Feral pigs venture onto nearshore seagrass meadows to forage and dig for crabs, mussels, fish, and seagrass rhizomes during low tide. Adult pigs have been reported "fishing" in the seagrass in water depths to their shoulders, some diving for a couple of minutes. Near Manuka (Tongatapu), the fishing pigs have become so popular, tourist information signs have been erected. The pigs are called "Captain Cookers", as it is thought that they are descendants from the animals James Cook took on his journey in 1770. Meat from the animals has also become a local delicacy, said to be saltier than normal, and fetching a premium price.

3.3. Regulating SCPs

The only regulating contribution that was perceived present across all regions was sediment stabilization (Fig. 2); which was also the only regulating contribution perceived to occur in Polynesia. Although this premise has not been explicitly tested, data from tropical Caribbean islands found that beaches without the protection of healthy seagrass meadows had higher rates of coastal erosion (James et al., 2019). The next most frequently occurring regulating contributions were Carbon sequestration (Fig. 4g) and Natural hazard regulation/Coastal protection. Overall, the differences in the perceived provision of regulating SCPs, appears a consequence of the seagrass genera present. Larger sized and persistent seagrass genera (e.g. *Enhalus*), with large thick broad leaves, large rhizomes and high biomass, are perceived to provide greater baffling of wave action and contribute significantly more to sequestration of carbon. Small-bodied colonising and opportunistic genera (e.g. *Halophila*) with small, thin leaves, small rhizomes and less

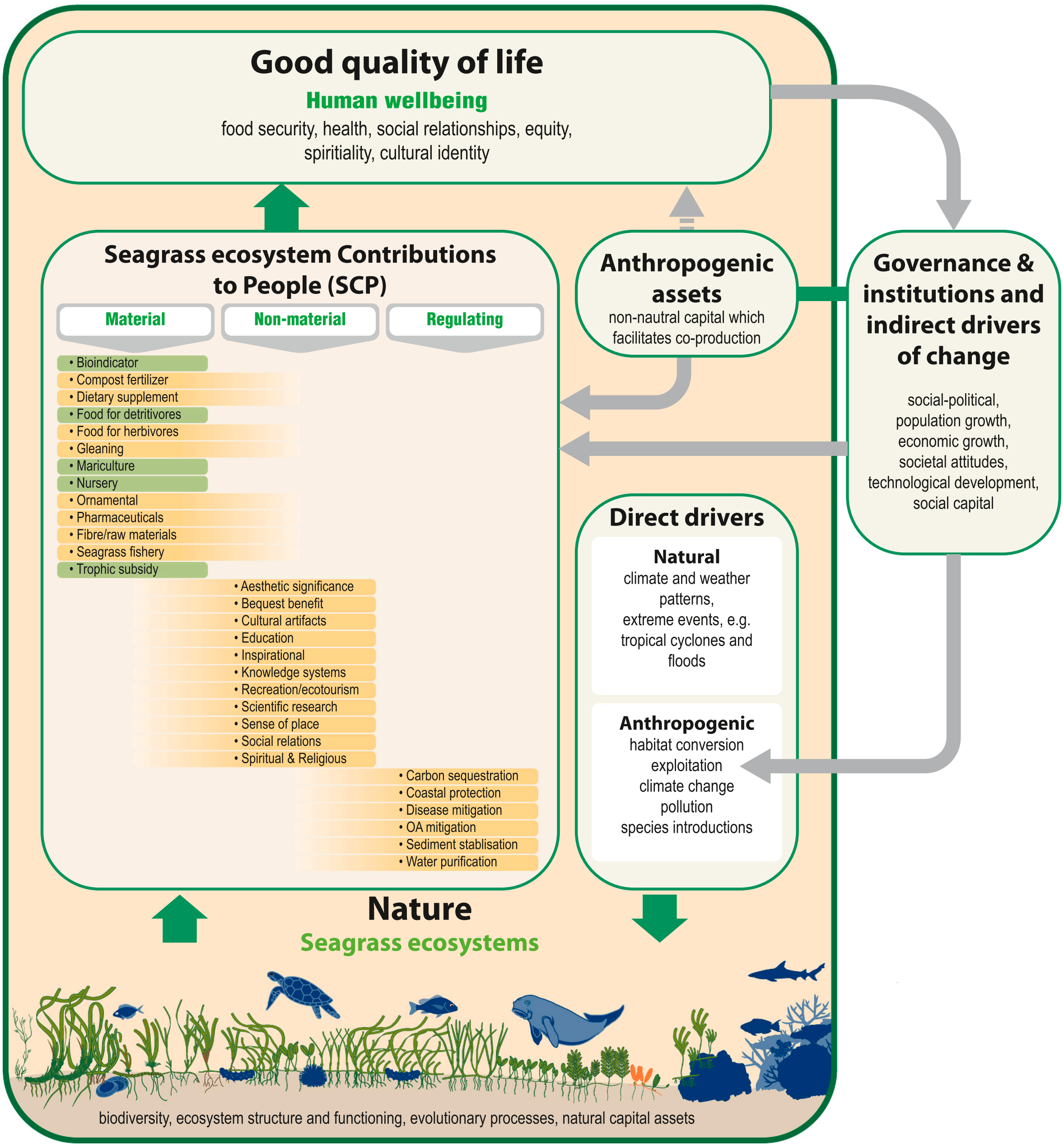

Fig. 5. Generalizing perspective on seagrass ecosystem (Nature's) contributions to Pacific Islands people within the IPBES conceptual framework: **Nature.** seagrass ecosystems (the natural world); **SCPs.** the goods and perceived benefits (or detriments), that people obtain from seagrass ecosystems to achieve a good quality of life; **Institutions and governance systems and other indirect drivers of change.** The underlying causes of change generated outside seagrass ecosystems (Nature), as a result of the ways in which people and societies organize themselves and their interactions with Nature; **Anthropogenic assets.** Additional contributions and ecosystem disservices derived from human interventions (i.e. co-production); **Direct drivers of change.** Anthropogenic are those that are the result of human decisions and actions, Natural are those whose occurrence is beyond human control; **Good quality of life.** The achievement of a fulfilled human life. Modified from Turner et al. (2014) and Díaz et al. (2018). Symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols/).

biomass, are perceived to have significantly lower ability to provide a regulating contribution.

3.4. An NCP framework for seagrass ecosystems

The contributions from seagrass ecosystems to people (i.e. SCPs) can often be difficult to categorise into a single component, as the majority of SCPs overlap to some extent (Fig. 5). This is particularly evident for Non-material contributions which overlap with either Material or Regulating SCPs, depending on the goods, benefits or detriments. For example, the recreational activity of observing charismatic megafauna such as dugongs or sea turtles in seagrass meadows is classified as a Non-material SCP, however when such activities are commercialised through tourism, the component includes Material SCPs because of the monetizing of the activity. Similarly, food related contributions (e.g. seagrass fishery, gleaning, *etc*) greatly overlap with Non-material SCPs, as food influences culture in various ways such as through tradition, religion and social relations. This influence, can also manifest detrimentally. For example, in Kiribati, green sea turtles were never eaten during times of war or crisis because it was believed to cause cowardice; on account of the turtles crawling habit (Johannes and Yeeting, 2000). Similarly, the consumption of turtle flesh was taboo to pregnant women, as it was believed to inform a mother's milk with the spirit of cowardice (and the trait passed to their unborn), and when consumed in large quantities supposedly encouraged tertiary yaws in children (Grimble, 1933). These overlaps are not surprising, as the close culture connection between SCP components is common across the Pacific Islands and it is embedded within people's cultural identity and wellbeing, i.e. good quality of life. Co-production through human interventions (Anthropogenic Assets, Fig. 5) can also increase ecosystem contributions (or disservices). For example, the seagrass fishery depends on the availability of fish stocks, which depends on high-quality habitat (natural capital). But fishing also depends on vessels and gear (manufactured capital, backed by financial capital), and on the skills and experience of fishers (human capital, knowledge) (Outeiro et al., 2017). The influence of co-production on the NCPs depends on the level (e.g. wild harvest versus cultured) and the means (e.g. simple, low technology versus highly mechanised). The higher the level and means, the greater the governance and management institutions (social capital, Fig. 5) needed to manage the sustainability of the fishery (and fish stocks). Across the PICTs, the seagrass fishery is predominantly wild harvest by simple means (low tech), and as a consequence has been shown to be successfully managed through mechanisms such as Local Marine Managed Areas (LMMAs).

3.5. Ecosystem valuation

In recent years, there have been several attempts to monetise seagrass ecosystem goods and benefits, as this can be a powerful way to ensure ecosystem contributions are valued and represented in management and policy decision processes. Use or market (Direct, Indirect or Option) and Non-use (e.g. Existence and Bequest) values can be estimated using a variety of techniques (Perman et al., 2011). Economic valuation of marine and coastal ecosystem services has been conducted for a number of PICTs (including CNMI, Fiji, Kiribati, Solomon Islands, Tonga and Vanuatu), but SCPs have been either overlooked or limited to regulating contributions (Arena et al., 2015; Gonzalez et al., 2015; Pascal et al., 2015; Rouatu et al., 2015; Salcone et al., 2015). For example, O'Garra (2012) estimated the economic value of the main goods and services provided by coral reefs and mangroves in the Navakavu traditional Fijian fishing ground to be USD 1,795,000 per year, but failed to mention the extensive seagrass meadows which occur there (McKenzie and Yoshida, 2020). In the Solomon Islands and Vanuatu, seagrass has been valued alongside other coastal ecosystems (e.g. mangroves and coral reefs), for their contribution to coastal protection, however the level of contribution by seagrass specifically is unclear (Arena et al., 2015; Pascal et al., 2015). Also, the economic value of carbon sequestration by seagrasses is hindered across the PICTs by a lack of reliable estimates of seagrass spatial extent and species composition; except for Vanuatu, where it has been estimated at USD 402,600 annually using a global average sequestration rate (Pascal et al., 2015). Broader socioeconomic valuations have been conducted, but these are limited. For example, the ecosystem contributions from seagrass in CNMI have been estimated at USD 10,333,872 annually, with the most valuable being Foreign Tourism (78%), followed by Recreation (11%) (Eastern Research Group, 2019). Comprehensive valuation of SCPs identified across the PICTs requires detailed local research and significant on-ground support (including financial). There are a number of valuation approaches (e.g. production based, cost based, and benefits transfer) and methods (e.g. fisheries valuation, restoration costs, mitigation costs, *etc*) that can be implemented to determine the Total Economic Value of SCPs (Christie et al., 2012). The most challenging will be non-use values (i.e. non-market) which cannot be easily measured in dollar terms, and require revealed or stated preference techniques such as hedonic pricing or contingent valuation and choice modelling, respectively. The close connection between Pacific Islanders and nearshore seagrass ecosystems suggests that alternatives to monetisation, such as consultative, participatory and benefit relevant indicators, may also need to be explored to enhance the accuracy of social evaluations (Christie et al., 2012; Olander et al., 2018). Nevertheless, while a lack of price does not imply lack of value, it often results in lack of 'visibility' or inclusion particularly regarding governance and policy (Farr et al., 2016).

3.6. Policy

Seagrass ecosystems across the PICTs are recognised as important marine habitats, however they are often underrated and marginalised in marine policy. Facilitating the conservation of seagrass ecosystems requires strong policies. Detailed information on seagrass ecosystems across the PICTs has been limited, and therefore the evidence underpinning policy and management decisions is often from external paradigms. Although these can act as a credible substitute in the interim, they ultimately require strengthening with evidence from comparable species and habitats (ideally local). Too often, evidence comes for unrelated species and habitats from outside the tropical western Pacific, which respond differently in their resistance to pressures and capacity to recover. For example, applying global carbon sequestration rates to tropical opportunistic and colonising species can undermine the scientific credibility of the initiative and should be used with extreme caution.

Across the PICTs, there is a critical need to develop policy in a local context, using Pacific Island examples from similar habitats so it can be used by coastal resource managers to promote the integration of SCPs into evidence-based decision-making. Similarly, the nuances of some conservation initiatives are often far removed from immediate local needs. For example, the representation of "natural capital" to be used in the accounting of carbon emission and sequestration is currently dominating the scientific and policy discussions around seagrass in the PICTs. Across the PICTs, the spread of policy ideals via colonial and wealthy country influences or international coalitions has resulted in policy enthusiasm regarding blue carbon. Using blue carbon valuations to encourage stewardship payments is an effective pathway for conservation, however, the primary focus of seagrass as blue carbon tends to sideline dialogues and policies emphasizing customary tenure, access and benefits for local people's livelihoods and immediate wellbeing needs, i.e. blue carbon blindness.

The achievement of good quality of life for Pacific Islanders, and the vision of what that necessitates from seagrass ecosystems, directly influences governance and institutions and other indirect drivers of change through policy actions (Fig. 5). With 95% of the PICT population (excluding PNG) living within ten kilometres of the coast (McKenzie et al., 2021), socio-economic and socio-cultural forces are indirectly driving human activities which are placing significant direct pressures on seagrass ecosystems. These threatening activities in concert with climate change, are resulting in multiple and cumulative stressors which can degrade seagrass ecosystems and their contributions. The management of coastal areas can be complex, and depends on the ways in which people and societies organize themselves and their interactions with nature. While resolving governance and the sharing of powers and responsibilities can sometimes be unclear, in the PICTs this is also further complicated by the strong customary tenure and management practices primarily vested with the traditional custodians. The requirement to meet international agreements and the sustainable use of resources, while balancing the needs of various stakeholders and respecting traditional arrangements for hunting and extraction, can be challenging as these are the root causes of the direct anthropogenic drivers that affect nature; influencing all aspects of relationships between people and nature (Fig. 5).

Although scientific evidence can inform policy, it is the local communities (constituents) that are the political influence. Building scientific literacy and awareness encourages confidence and involvement of local people in decisions that affect them. Co-production and constituent participation in evidence-base gathering can eliminate barriers and shift community thinking so that the wider public are aware of the problems facing seagrass resources. This helps to create a shared understanding of how seagrass damage can impact the economic, cultural and ecological values of our marine resources. The benefit is greater environmental stewardship, which, in turn, will empower Pacific Islanders to contribute more widely to public policy formulation and debate on environmental issues at not only the local but national and global scales. Some PICTs are progressing in this awareness raising and capacity building through initiatives such as rewilding nearshore areas (e.g. seagrass restoration “Meadows in the Sea campaign” in Fiji (Curuqara, 2020)).

To strengthen the conservation of seagrass ecosystems and their contributions to people’s quality of life in the PICTs, we recommend the following broad policies:

- Securing and integrating customary fishing rights and traditional marine tenures, such as LMMAs, in the governance and management of seagrass ecosystems;
- Focusing regional effort to address data gaps in a coordinated approach, such as mapping seagrass meadows across the PICTs;
- Supporting socio-economic and cultural valuation of seagrass ecosystems and their contributions to people;
- Supporting the gathering of local specific scientific evidence;
- Supporting knowledge co-production activities;
- Ensuring seagrass ecosystem research is relevant, by not only providing data and knowledge, but also providing convincing arguments or concepts that enhance policymaking, look more holistically at solving coastal issues and are socially acceptable;
- Ensuring monitoring information will also support the formulation of specific policy to manage multiple pressures and assess cumulative impacts;
- Encouraging through incentives the publishing of results in peer reviewed journals, to circumvent marginalization of information to gray literature;
- Increasing effort to translate science into policy;
- Encouraging scientists and policy makers to work together to couple knowledge (evidence base) with legislation and ensure informed decisions are translated into sound practice for people to drive social change;
- Ensuring policy-making is open and receptive for scientific advice and public scrutiny, and integrated with existing and planned conservation policies;
- Support novel initiatives which enhance seagrass ecosystem resilience or rewilding;
- Building scientific literacy and awareness through outreach initiatives to ensure confidence and local stewardship.

4. Conclusions

In conclusion we find that seagrasses are of immense importance to the people of the PICTs, both historically and in the present day. Of the 32 SCPs reported for seagrass globally, 30 were present or perceived as present in the PICTs. The number of SCPs was higher in Melanesia, than Micronesia and Polynesia, respectively. We find that Melanesia has a closer cultural connection to seagrass ecosystems than Micronesia and Polynesia. In Melanesia, seagrass occurs in every country and territory, the seagrass species richness is greater, and the presence of structurally larger persistent seagrass genera is greater. Melanesia is also both geologically and culturally older, with human settlement occurring earlier than in the other Pacific Island regions. Micronesia also has a higher occurrence of seagrass, higher species richness (including persistent species), and longer human settlement, and as such it records the second highest number of SCPs, while Polynesia the least. Polynesia is the youngest of the Pacific Island regions, both geologically and in terms of human settlement, and has the lowest occurrence of seagrass, which is dominated by structurally smaller colonising species.

Capitalising on the close cultural connection between people and seagrass ecosystems provides a mechanism for empowering local peoples and building political influence to strengthen policy and conserve seagrass ecosystems and the contributions they provide to the quality of life of Pacific peoples.

CRediT authorship contribution statement

Len J. McKenzie: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Rudi L. Yoshida:** Conceptualization, Methodology, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing. **John W. Aini:** Investigation, Writing – original draft. **Serge Andréfouet:** Investigation, Writing – original draft, Writing – review & editing. **Patrick L. Colin:** Investigation, Writing – original draft. **Leanne C. Cullen-Unsworth:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Alec T. Hughes:** Investigation, Writing – original draft. **Claude E. Payri:** Investigation, Writing – original draft, Writing – review & editing. **Manibua Rota:** Investigation, Writing – original draft. **Christina Shaw:** Investigation, Writing – original draft, Writing – review & editing. **Roy T. Tsuda:** Investigation, Writing – original draft. **Veikila C. Vuki:** Investigation, Writing – original draft, Writing – review & editing. **Richard K.F. Unsworth:** Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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