Chapter 6
The Water-Food Equation in the Pacific

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Complexities that exist at the water-food nexus typify the challenge, and the opportunity, for the Pacific region in adapting to a future of change.

Abstract On land and in the sea clean water safeguards food and nutritional security in the Pacific, because it underpins functioning, productive food systems, and human health and wellbeing. Water, food, and communities in the region are intrinsically connected, which makes resolving ecological and socio-economic issues an inherently complex task. Yet, this connectivity, and the geographic diversity of Pacific nations, is also a strength. Nexus solutions can be effective in increasing the sustainability of resource use and the resilience of ecosystems and communities to climate change, as they enable a range of interconnected land and sea ecosystem issues to be considered across multiple spatial scales. They also support communities, governments, and industries to identify and navigate trade-offs in social and ecological objectives. This chapter explores challenges in the water-food equation and several nexus-focused strategies that could foster sustainability and the resilience of ecosystems, resources, and communities in the Pacific.

Keywords Water resources · WASH (water, sanitation, and hygiene) · Food production · Food systems · Climate resilience · Sustainability

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A. Dansie et al. (eds.), *The Water, Energy, and Food Security Nexus in Asia and the Pacific*, Water Security in a New World,
https://doi.org/10.1007/978-3-031-25463-5_6

6.1 Introduction

The productivity and sustainability of water and food resources and the health of ecosystems are interconnected. Because of this interdependency, challenges in achieving sustainability that arise at the water-food nexus can be complex, and they can require multiple ecological, social, and economic needs to be met. In the Pacific, these challenges and complexities also solidify into a single significant test; without a secure supply of clean water, on land and at sea, food security as well as water security, cannot be achieved. Clean and secure freshwater and marine environments are central to the water needs and sanitation of Pacific communities, and they underpin the productivity, safety, and nutritional value of food. Without clean freshwater and sanitation (SDG 6) communities will experience ongoing impacts to health and well-being, and pressure on the supply of water for land-based food production will escalate due to population growth, competing demands for resources, and climate change. To conserve marine and coastal environments and achieve genuine ecologically sustainable development of resources (SDG 14) healthy ocean waters are essential.

Across the Pacific diverse environmental settings mean that access to sufficient quality and quantity of freshwater is highly variable (Chap. 2). For example, in atoll nations like Tuvalu, the Marshall Islands, and Kiribati, freshwater is in limited supply, and technological and traditional approaches to cope with water scarcity are required to sustain food production and human communities, particularly during dry spells and droughts (MacDonald et al. 2020). In contrast, in Melanesian countries like Papua New Guinea, Solomon Islands, Vanuatu, and Fiji, freshwater is abundant, but the quality of the resource, particularly during and in the aftermath of significant extreme weather events, represents a major threat to human health and the safety of food products (Chan et al. 2020). In all geographies coastal environments and resources make an important contribution to food, livelihood, and community well-being. But degradation of catchments and coastal water quality, brought about by poorly managed development, land-based pollution, and high levels of water consumption threaten these ecosystems and their productivity (Halpern et al. 2015). Human stressors such as eutrophication, overfishing, and pollution, including threats from plastic, light, sound, nutrients, and GHG emissions, are impacting marine and coastal habitats and species at an increasing rate, and climate change is exacerbating their effects (Halpern et al. 2019).

The biogeographic processes that shape geographies in the Pacific mean that many environments are well adapted and inherently resilient to natural disturbance—resilience that has evolved over millions of years—but poorly adapted and highly vulnerable to human-driven impacts (Keppel et al. 2014). Development that increasingly reflects western expectations for water and food systems, especially intensive, high output production systems, and the loss of Indigenous knowledge and practice (Chap. 11) is straining the natural coping capacity of these systems and human communities (Crook et al. 2015). This chapter explores challenges for Pacific nations in the water-food equation and several nexus-oriented strategies that target challenges in sustainable resource use, but could also provide an opportunity to leverage the interconnected nature of water and food systems to deliver numerous ecological, social, and economic outcomes across many spatial scales.

6.2 Water-Food Systems: Their Importance and Their Challenges

While at a global level the drivers of impacts to the availability and quality of water may be common (e.g., water extraction for increased food production, physical effects of climate and natural hazards) they are unique in time and place throughout the Pacific, insofar as how and to what extent the effects are experienced at regional, national, and subnational levels. Pacific nations are exceptionally diverse, geographically, biologically, and culturally. This diversity is an important feature of adaptable and resilient environments (Keppel et al. 2014), but it also exposes the variability with which nations, particularly the Pacific Island Countries and Territories (PICTs), experience the effects of resource pressure and, increasingly, climate change. For example, the Marshall Islands experiences the effects of drought and sea level rise, both of which reduce the availability of freshwater (MacDonald et al. 2020), whereas flooding that occurs in the Solomon Islands each year generates an excess of freshwater, and most is unused because rainwater harvesting is not common practice (Chan et al. 2020). Such diversity of contexts requires consideration of issues that emerge from within water and food systems and the unique impacts they can have in each, and consideration of the effects they generate across these systems.

6.2.1 Water Systems

While water scarcity and lack of freshwater reserves is a growing problem in the central and eastern parts of the Pacific, many countries in the Western Pacific region suffer periods where monsoonal rainfall creates very different problems. Where freshwater is abundant, careful consideration of the sources of water and their potential contamination is needed, to ensure that communities use safe water for drinking and food production (Elliott et al. 2017; Chan et al. 2020). While interventions supporting the capture and austere use of rainwater, universally deemed to be the safest and highest quality source of water in most settings, are gaining significant support from government and non-governmental organizations (NGOs) (MacDonald et al. 2020), there remain cultural and biophysical constraints in many places that are limiting the success of such interventions (MacDonald et al. 2017; Chan et al. 2020).

Scientific knowledge of water resources remains scarce in many Pacific settings, such that the quantity and quality of freshwater available to a large number of communities remains unknown (see Chap. 2 for discussion on water resource security). An effective understanding of country-specific and community context remains a barrier to supporting water-food security and achieving the SDGs, particularly as traditional knowledge and cycles of rainfall are no longer as reliable as they once were (Hadwen et al. 2015; Chan et al. 2020). Limited understanding of groundwater recharge and streamflow rates also represents a constraint in water resource planning in many locations, although in some places sufficient information via qualitative information, including anecdotes, government and NGO reports exists to understand if water is scarce across seasons or other time scales.

With year-to-year rainfall variability increasing, there will be growing uncertainty around predictions of rainfall and reliability of freshwater resources for Pacific peoples (Chap. 5). Already, this lack of predictability in rainfall cycles is having an impact on local food production in many countries. Anecdotal evidence suggests that the timing and magnitude of reliable rainfall events has been diminished, and many local people have spoken of failed taro crops and uncertainty around when to plant (Sahin et al. 2021). This erosion of reliability threatens the continuation of subsistence production systems that many Pacific Island peoples rely on for sustenance. Furthermore, changes in rainfall cycles could see an emergence or increase in other threats, such as bushfire events, increased vulnerability of crops, particularly banana and plantain, to fungal disease, and the additional pressure on water resources and infrastructure required for adequate response. Bushfires experienced throughout Australia in summer 2019/2020 and flooding in the summer of 2021/2022 make clear the extremity of the impacts of climate change; impacts that are projected to become more common in many places (IPCC 2019, 2022). Bushfires in the PICTs present a growing threat, and for water and food systems their impacts are numerous. The physical impacts to natural resources supporting primary production can be acute (e.g., loss of crops or stock and sustained effects on water resources through use of water during events), as can contamination of water sources which can impeded recovery. Additionally, heavy rainfall events after bushfires can lead to erosion in catchments and carry sediment to coastal areas. Sedimentation of critical coastal and marine habitats such as coral reefs can lead to further environmental impacts and rapidly and severely deteriorate marine food source systems. To adequately prepare for the increasing threats and effects of bushfires, similar approaches used to responsed to address other natural hazards, such as cyclones, will be needed. But there will also be unique, differentiated needs for preparation that must not be overlooked, in particular, access to additional water supply, especially during times of higher bushfire risk, and rapid response to the ways in which supply will be destabilized and quality impacted.

While living with freshwater resources of limited quality or quantity represents a constraint for many people in the Pacific, there are also countless examples of Indigenous adaptations that help communities survive during periods of scarce supply. For example, in the Republic of the Marshall Islands, communities use seawater when cooking their fish (Elliott et al. 2017); this not only preserves the traditional Indigenous way of preparing food, but also preserves the limited available freshwater for drinking use only, which helps the community get through dry spells and droughts (MacDonald et al. 2020). Including Indigenous and customary practices and knowledge into the design of sustainability and climate change adaptation strategies will ensure the ecological and social uniqueness of the Pacific region remains a strength, and increase the capacity for adaptation under a future of change (Sahin et al. 2021).

6.2.2 Food Systems

In the PICTs, changes in eating habitats have resulted in poorer nutrition, the effects of which will be intensified by threats to food security via disruptions to supply chains from climate change. This includes direct impacts to food production, but also disruption to distribution networks and the economic capacity of households to access food (Barnett [2011], and see Chap. 4 for discussion on food and nutrition security). However, despite ubiquitous and sometimes high rates of food imports around 80% of people in the PICTs still draw on agriculture from small landholders to satisfy their daily food needs. Many households have small food producing gardens and these small holder farms play a pivotal role in the stability and quality of supply (Georgeou et al. 2022). Agriculture and seafood production (fishing and aquaculture) also provide the largest source of employment in the region, providing a societal basis for both economic and food security, especially economic security created by small-scale or subsistence fisheries which account for most of fisheries livelihood fisheries in the Asia–Pacific (Kittinger 2013). These dependencies underscore one of the most significant feedback loops that must be addressed in food production today. An estimated 70% of freshwater usage, 80% of habitat degradation, and 26% of total global greenhouse gas (GHG) emissions are associated with global food production (Poore and Nemecek 2018). In the absence of practical or technological advancements to address the environmental impacts of food systems, impacts to resources could increase by 50–90% in the coming years (Springmann et al. 2018). Under these circumstances food and nutritionally insecure nations could face the double jeopardy of needing to expand production to meet increasing demand while also incurring the impacts of increased production, through continued deterioration of water resources, land displacement, and biodiversity loss (Blanchard et al. 2017).

The island nature of the Pacific region lends itself to an important role for seafood, which forms an essential part of diets and cultural and economic livelihood. Oceania maintains the highest regional per capita consumption of seafood globally (an average 24.2 kg per capita), and the contribution of fish and fishery products to the supply of animal protein is more than 20% in a number of countries (FAO 2020). For several small island nations, such as Palau, the Cook Islands, Kiribati, and Tokelau, alternative forms of protein are not readily accessible and so consumption can also be synonymous with reliance.

Small-scale fisheries do and will continue to play a critical role in securing this consumption, even with the effects of climate change (Golden et al. 2021; Short et al. 2021). However, the current distribution of seafood production effort means this reliance is overwhelming directed toward fisheries, which exposes resources to overfishing and the challenge of meeting social objectives for food security at the same time as enabling economic opportunities, such as engaging with export markets. While production of seafood from aquaculture and its contribution to human consumption has steadily increased since the 1960's at a global level, with the total global volume of production from this industry now equivalent to fisheries, at a regional level this same trajectory of growth has not occurred. Aquaculture production in Oceania is limited in comparison to other regions, with approximately 12–14% of total seafood production (fisheries and aquaculture combined) contributed by aquaculture and decadal growth occuring at a rate of just over 4% (FAO 2020). While the majority of the Pacific has suitable habitat for aquaculture production of marine species, and for a greater diversity of species than that currently produced (Oyinlola et al. 2018), this generally restricted scale of current activity suggests there are multiple technical, regulatory, and social challenges that need to be overcome to increase production from this industry. Whether a country practices aquaculture or not, and to what extent, is influenced by socio-economic factors, particularly the quality of governance and regulation, and development of this industry over time, underscoring the important role these factors will play in enabling sustainable growth into the future (Gentry et al. 2019; Ruff et al. 2020).

6.2.3 Ecosystems and Economies

Traditional ways of life in the Pacific are dependent on nature, and these cultural ties, as well as the physical dependence, are critical to wellbeing. For example, biodiversity is fundamental to healthy ecosystems, but it is also closely tied to important avenues for economic productivity, deepening the dependence of the Pacific on healthy and productive water-food ecosystems, and adding to the complexity of balancing multiple community and environmental needs. In particular, marine environments in the central Indo-Pacific have the highest species richness globally (Miller et al. 2018) and this unique biodiversity underpins the opportunities afforded through tourism. Across Asia and the Pacific, international tourist arrivals have steadily increased since 1950, and in 2018 the region received 24.43% of arrivals worldwide (Roser 2017). Yet, while of critical economic importance tourism is a significant creator of waste and the pressure generated through additional use of water resources can limit the availability and access to safe water resources for residents (Becken 2014; Dwyer 2018). Energy-intensive desalination plants (Chap. 8) often only serve international guests, with no direct water benefits for the local communities (Loehr et al. 2021). These interactions could constrain sustainable development of tourism and other industry, and further growth of economic capacity (Briassoulis 2002). As such, a more holistic and integrated approach is needed to ensure that growth and development in the tourism sector does not come at the cost of the local environment, people, or places (Briassoulis 2002; Loehr et al. 2021). As climate change places increasing stress on water resources, location-based or 'destination' approaches will need to be able to ensure the sustainability of tourism in climate-vulnerable nations (Hadwen et al. 2015; Loehr et al. 2021).

Similarly, food consumption by tourists can generate expectations for access to different foods than those produced in local systems and imbalances in food availability, which contributes to the high rates of food importation observed in some Pacific nations (Table 6.1). Food importation requires considerable infrastructure. Where trade networks lack infrastructure or the capacity to sustainably increase the supply of goods from domestic or international markets, there is a risk that attention and funding for maintenance, upgrades, or new initiatives will be diverted toward tourism-centric development and away from needs that best serve local communities. In the short term, the challenges of achieving local water and food security while restoring and increasing economic opportunities associated with food markets and tourism have been complicated by the impacts of the COVID-19 pandemic. The collapse of the tourism economy and reduced economic contributions from fisheries will create long-term debt for many nations (Béné 2020; Northrop et al. 2020) upping the challenge of meeting numerous, sometimes competing, ecological, social and economic demands.

Unfortunately, a comprehensive and harmonized picture of ecological and human-development risk in water-food systems across the Pacific is being compromised by a lack of available data for many PICTs. These data gaps limit the capacity for planning, and comparison of threats and impacts at successive scales to appropriately prioritize investment. For example, the 2019 Global Food Security Index reports rankings for the Pacific nations of Australia and New Zealand, but, despite being a high profile and widely used database, comparable data and scores for many PICTs are not available. This creates an imbalance and bias in the world view of resource vulnerability analyses. Data limitations for the Pacific region also limit down-scaled assessments of climate risk. For instance, Faivre et al. (2022) completed a hazard assessment in Port Resolution Bay, Vanuatu and found very limited data of sufficiently high resolution to model coastal processes effectively, leading to the risk of

Table 6.1 Proportion (%) of key trade processes (consumption by tourists, importation of products, and exportation of products) in 2017, associated with food production (including food, beverages and oils) in select Pacific nations (FAO 2019; Roser 2017)

Country[a]	International arrivals in 2016	Total food production (tonnes) in 2017	Tourist consumption (% of production)	Imports (% of production)	Exports (% of production)
Fiji	792,000	2,312,000	10.38	16.61	11.16
French Polynesia	192,000	230,000	17.83	68.26	3.91
Kiribati	NA	367,000	24.52	7.90	26.70
Samoa	134,000	293,000	19.11	23.89	6.14
Solomon Islands	23,200	1,059,000	17.19	11.71	15.49
Vanuatu	95,100	529,000	11.91	9.26	30.06

[a]Countries included are those with available data for consumption of food and beverages by tourists

recommending maladapted approaches. In this example available wave data generated unrealistically high predictions of wave height within the bay, which if taken on face value would lead to a recommendation for extensive and expensive engineering adaptation for coastal protection despite these solutions being likely to fail to prevent ongoing cliff erosion, even under worst case scenarios associated with a Category 5 tropical cyclone. The most appropriate intervention identified by Faivre et al. (2022) was revegetation of clifftops to reduce erosion, a solution that may be lower in immediate and ongoing costs and come with numerous additional ecological and social co-benefits.

6.3 Fostering Sustainability and Resilience Through Water-Food Strategies

The Pacific region is physically, socially, and economically exposed to acute impacts and disruptions from climate change as well as systemic changes, such as sea level rise and species migration through changes in the suitability of habitat (IPCC [2019] and see Chap. 5 for climate change trends). Furthermore, climate change strains the connectivity between systems, displacing or accumulating pressure across ecosystems or communities. Changes in rainfall patterns present direct threats to water security because of the high dependency of many Pacific nations on rainfall due to limited availability of ground and surface water (Chap. 2). Changes in rainfall patterns will likely also impact the production of staple crops, which could exacerbate the burden of malnutrition that is already present in the region (Chap. 4). Such changes have direct impacts and equally problematic indirect impacts. For example, reduced freshwater inputs into catchments can reduce flows to coastal habitats that are necessary for the breeding of commercially or culturally significant freshwater and migratory marine fishes (Arthington et al. 2016). Engineering features designed to mitigate the impacts of increased variability in freshwater resource availability in response to climate change could, therefore, disrupt these natural processes (Crook et al. 2015). Strategies that therefore target the interdependencies between water and food systems will be especially effective in supporting climate adaptation and resilience. Their efficacy is reliant on working across ecosystems, spatial scales, and human dimensions, and the interdependencies become an opportunity to leverage improvements in both systems, their interdependencies, and diversity, which is critical to environmental health and community wellbeing (Fig. 6.1). Below we discus three strategies that may be especially valuable examples of a nexus approach to water and food sustainability in the Pacific region. We identify some key considerations for each that all actors could take in furthering these approaches.

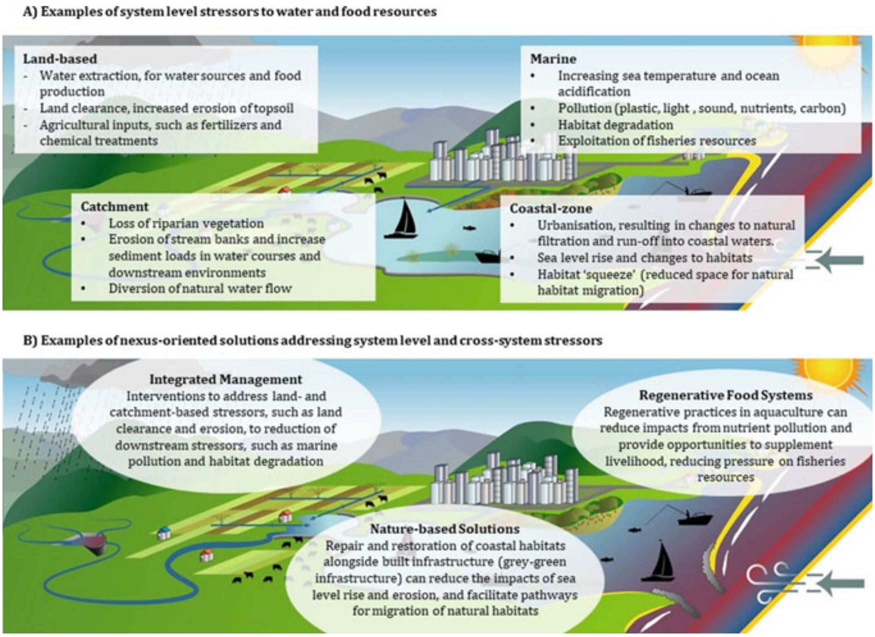

Fig. 6.1 Water-food nexus strategies provide an opportunity to address threats within and across systems (A), through sustainability strategies that work across multiple ecosystems, spatial scales, and human dimensions (B). Figure adapted with permission from A. Blacka and the Water Research Laboratory, University of New South Wales

6.3.1 Integrated Planning and Management

Integrated Management (IM) of resource use and sustainable development is now a generally well-known and promoted approach; and it remains one of the most important ways to achieve effective and equitable outcomes at the water-food nexus. IM can assist to make decisions that require balancing multiple objectives in sustainability, or the need for trade-offs, providing a foundation for transparent governance and decision-making. The importance of this approach is reflected in its explicit inclusion in the SDG's and their targets, including SDG 6: Clean Water and Sanitation, which identifies "Target 6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate". Integrated Landscape Management (ILM) is the management of production systems and natural resources in an area large enough to produce vital ecosystem services, and small enough to be managed by the people using the land and producing those services (FAO 2017). This definition is extended to catchment and marine applications. In coastal areas, Integrated Coastal Zone Management (ICZM) can play an important role in managing human use of this highly dynamic space, and changing expectations for use of these common property areas and resources.

The value of integrated management, in all its forms, is the focus it adds to planning at the landscape or seascape scale, which drives recognition of the myriad habitats, species, and functions that form an ecosystem and the intent and impact (positive and negative) of a community's interactions with them. An integrated approach also enables challenges such as poverty and food security to be considered alongside efforts to protect or restore environments. Yet, IM has proven difficult to implement, in part because sufficient investment has not been directed toward the capacity needed to monitor and evaluate its efficacy and make adaptations (in the approach), and because it is linked to legislation and jurisdictional cross boundary policy (e.g., catchment management), which requires sustained political will and support from government. Even in areas where IM constitutes a guiding principle for legislation it has had mixed success. Notably, despite having the regulatory and management capacity to implement ICZM, its application in Australia is varied and its results uncertain. This has contributed to the lack of progress made in addressing ongoing declines in globally critical habitats, such as coral reefs and biodiversity (Clark and Johnston 2017). Disconnect in the practices applied in coastal areas and an imbalance between responsibilities and effective resourcing has also meant that complex but increasingly urgent issues, such as sea level rise, are not yet being meaningfully addressed.

The island nature of the PICTs creates the added challenge of realizing integrated management in areas physically disconnected but intrinsically linked, be these linkages in ecosystems, species, or socio-economic and cultural connections. Integrated Island Management (IIM) has been put forward as an approach to this complexity (Jupiter et al. 2014). This work identified ten principles that provide a valuable framework to advance IIM throughout the Pacific:

1. Adopt a long-term, integrated approach to ecosystem management.
2. Use clearly defined boundaries for ecological and governance systems.
3. Maintain and restore connectivity between complex social and ecological systems.
4. Incorporate stakeholders through participatory governance with collective choice arrangements that consider gender and social equity outcomes.
5. Ensure that management rules reflect stakeholder values and conditions.
6. Ensure recognition of rights to organize and develop management rules.
7. Develop appropriate sanctions for users who violate rules.
8. Identify appropriate, efficient, and cost-effective conflict resolution mechanisms.
9. Implement adaptive management where regular monitoring, evaluation, and review in the face of uncertainty lead to evidence-based decision-making.
10. Nest management layers across sectors, social systems, and habitats.

Importantly, the inclusion of Indigenous knowledge and customary practices in sustainability and climate change adaptations (Chap. 11) can inform the design of more effective solutions, in addition to having a positive effect on individual and community wellbeing (Sahin et al. 2021). Indigenous knowledge is not, however, currently well-included in integrated approaches, and practical, 'on the ground' examples of Indigenous-led or informed strategies are rare (see Nalau et al. 2018 for a recent review of case studies). To implement IM effectively, the inclusion of Indigenous and customary knowledge and practices must be a priority, and actively pursued.

6.3.2 'Ridge to Reef' Investment

When implemented effectively IM can assist to more efficiently direct interventions and investment. 'Ridge to Reef' (Chap. 16) resourcing of sustainability and climate change adaptation strategies is built on an integrated approach but focuses especially on anthropogenic impacts from terrestrial areas, at the source, or top, of the watershed and their potential effects throughout the catchment and its waterways to the coast and ocean. Consequently, as well as enabling the source of problems to be identified a ridge to reef focus can facilitate a more accurate view of the cumulative nature of effects, such as the use agricultural fertilizers and runoff in addition to successive land uses and change (e.g., Carlson et al. 2019). For example, Delevaux and Stamoulis (2022) used spatial analysis of future forest management interventions to map where the greatest benefits of marine conservation in Vanuatu could be achieved. Priority areas for intervention in forests were clearly identified as those being upstream from coral reefs and seagrass in catchments, on the windward side of large high islands where tropical rainfalls were greater.

As well as having challenges common to the implementation of IM, a current barrier to a ridge to reef approach is the size of the 'pool' of funding that is currently available. Funding from global agencies and national jurisdictions provides a basis for solutions that are applied in catchments, but public funding is unlikely to generate an increase in investment or revenue that would lead to interventions being sustained over long periods of time, or scaled-up, because integrated approaches typically involve many stakeholders, each with their own changing interests (FAO and Earthscan 2011). Furthermore, funding of climate change adaptation and mitigation is currently well below what is required to effectively protect communities and ecosystems, particularly for strategies that can generate environmental as well as social outcomes. A recent assessment of major global climate funds found that while cumulative investment for climate change mitigation and adaptation projects was USD94 billion, only USD12 billion of this funding was being spent on Nature-based Solutions (NbS; UNEP 2021). Additional finance for adaptation is critically needed.

To supplement public funding, reform of financing and influencing the direction of investment from private entities is emerging as an important approach to build capital for NbS. For example, green bonds provide a financing option for private and public entities to support environmental investments by working to raise capital that explicitly supports environmental projects. The distinction of social values arising from the environmental value, often with links to climate change adaptation, arising from these investments differentiate them from traditional bonds (The World Bank 2015). From the first green bond in 2008 to the end of Jun 2015, the World Bank issued USD8.5 billion in more than 100 green bond transactions, supporting 70 climate projects around the developing world (The World Bank 2015). The first ever green bond issued by a developing country was issued by Fiji in 2017, as a sovereign bond focused on sustainable development of natural resources, renewable energy, water and energy efficiency, clean transport, wastewater management, and sustainable agriculture to reduce fertilizer run-off into coastal areas (The World Bank 2017).

In recent years 'blue bonds' have emerged to support financing of solutions for coastal resilience. Financing for blue bonds is being pursued for the Pacific with planning underway for a Pacific Ocean Bond (BNCFF 2019), meaning the region may be well positioned to capitalize on private investment and provide an ethically and financially attractive market for investors. Emerging financing mechanisms such as these could provide much-needed resources to implement adaptations throughout catchments and in high vulnerability areas, especially in the PICTs. A critical step in ensuring strategies can be effective is maximizing their value and cost efficiency. Embedding consideration of financing in IM at multiple spatial scales, using a ridge to reef approach, provides one of the best opportunities to address issues that impact multiple, connected terrestrial and coastal environments and dependent communities.

6.3.3 Nature-Based Solutions and Regenerative Systems

Central to the water-energy-food nexus is the environment (Chap. 1), with functioning ecosystem services essential for sustainable development. Interactions between the sectors of water, energy, and food do not necessarily physically abut each other to be connected at an ecosystem, catchment, or other scale. The pressures and impacts from each sector interact through pathways as part the broader environment. NbS are actions that protect, sustainably manage, or restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits (IUCN 2020). When applied to climate change, NbS could enable communities to achieve targeted climate mitigation outcomes, including GHG emissions reductions, while also realizing sustainable growth in the use and production of resources, especially water resources and food. Land management actions using these Natural Climate Solutions (NCS) may be able to provide more than one third of the mitigation required to keep climatic warming below 2 °C, and they may be more cost-effective than other approaches (Griscom et al. 2017). A range of NbS and NCS are emerging in agricultural settings and industries, including "regenerative practices"; practices that work to rehabilitate degraded land and reduce GHG emissions through specific farming approaches. The resource burden of global food production is significant, and transformation of this industry is needed. The Food and Land Use Coalition, Global Consultation Report (FOLU 2019) report defines 10 transformations that if implemented could create additional economic outcomes to 2030 worth USD530 billion, through actions that focus on 'productive and regenerative agriculture', and USD200 billion by 'restoring and protecting nature'. Importantly, NbS present an opportunity to bridge the intent of IM with practical and effective solutions for system-level interventions (e.g., improving soil health) and interlinked interventions that can have broader benefits (e.g., improving soil health to enhance food production, enhance biodiversity, and sustain local cultural values from the landscape).

An emerging illustration of how regenerative practices could foster increased food production while also improving water quality and ecosystem resilience can be seen in restorative aquaculture. It has been estimated that an additional 76 million people in tropical areas of Asia and Oceania could be fed on the high-quality protein provided by bivalve shellfish with an additional development of only 1% of the available (non-conflicted) waters (Willer and Aldridge 2020). However, the comparatively smaller contribution of aquaculture to total seafood production in Oceania (12 to 14%) and low growth rates over the last several decades (4%) present a challenge to increasing production from this industry in the short term (FAO 2020). Also, despite substantial progress in improving industry sustainability and management over the last 20 years issues associated with pathogens, parasites and pests remain, conflicting use of space and resources can be difficult to resolve, and the effects of climate change may present a challenge to the capacity of existing farming methods (Naylor et al. 2021). Therefore, while sustainable development of aquaculture might foster access to food and economic opportunities with minimal pressure to freshwater resources, and provide a means to produce quality protein with lower environmental impacts than terrestrial sources (Gephart et al. 2021), growth in this industry will most likely still increase the risk of environmental impacts, conflicts in resource use, and greater GHG emissions. In contrast, restorative aquaculture, "occurs when commercial or subsistence aquaculture provides direct ecological benefits to the environment, with the potential to generate net positive environmental outcomes" (The Nature Conservancy 2021). It provides an opportunity to direct growth in aquaculture for food or economic activity toward practices that can also generate ecosystem services and environmental benefits, and repair or protect coastal and marine environments. Bivalve shellfish aquaculture has been assessed as having 'high potential' for the parallel delivery of food and environmental benefits via restorative aquaculture in the Pacific (Theuerkauf et al. 2019, https://sites.google.com/view/globalaquatest/home), and interest in the production of seaweed species—an aquatic food that can be produced with the lowest known GHG emissions (Gephart et al. 2021) and provide a range of ecosystem services as co-benefits (Alleway et al. 2018)—is growing (Box 6.1).

To support effective implementation of NbS the International Union for Conservation of Nature (IUCN) has established global standards that provide a framework to support verification of the efficacy of solutions and guidance on their design (e.g., biodiversity and ecosystem considerations, financial viability, balancing trade-offs), and scaling, the 'IUCN Global Standard for Nature-based Solutions' (IUCN 2020). These standards directly and indirectly intersect with water and food industries. The synergies between aquaculture, for example, have been explicitly reviewed, showing that under specific circumstances, and if planned and implemented effectively, aquaculture could contribute to NbS (Le Gouvello et al. 2022). Regional initiatives are also emerging, such as the Kiwa Initiative (https://kiwainitiative.org/en/) which works to strengthen the resilience of Pacific Island ecosystems, communities, and economies to climate change through NbS. In partnership with the Pacific Community (South Pacific Commission) and the Secretariat of the Pacific Regional Environment Programme (SPREP), this initiative recently launched a technical assistance program aimed at:

- identifying and developing large projects addressing climate change adaptation through NbS;
- assisting relevant stakeholders from beneficiary PICTs in project development to be submitted to the Secretariat of the Kiwa Initiative; and
- promoting joint funding opportunities from the Kiwa Initiative and other climate action donors.

The availability of frameworks and support mechanisms such as these provide important guidance for industry, jurisdictions, and communities in immediately engaging with NbS and regenerative practices, and must continue to be developed and maintained. To ensure NbS can be implemented effectively, however, and without undue economic costs through inefficiencies or maladapted responses, collaborative, cross-jurisdictional collaboration that can support the implementation of IM and ensure the inclusion of Indigenous and local knowledge and customary practices in an equitable way, must be reinforced.

Box 6.1 Seaweed—nutritional outcomes with sustainable, environmentally positive food sources

Marine algae (seaweed) produced through sustainable aquaculture is gaining increasing attention for its potential to be a nutritionally valuable source of food that can also provide ecosystem services and environmental benefits during farming (Fig. 6.2). Seaweeds have a range of known co-benefits, meaning the sector could make an important contribution to food security as well as ecosystem health in Pacific. Barrett et al. (2022) estimated that a seaweed farm could remove an average 275 kg of nitrogen ha^{-1} yr^{-1} (n estimates = 8; 96–678 kg ha^{-1} yr^{-1}), worth an average 8,889 (3,084–21,886) USD ha^{-1} yr^{-1}, and there is the potential for seaweeds to use substantial amounts of carbon during their growth, to the extent that the carbon taken up could support offsetting emissions from the aquaculture industry as a whole (Froehlich et al. 2019). With the right practices seaweeds can be produced with very low GHG emissions and other environmental impacts (Gephart et al. 2021), and could therefore support communities in meeting the objectives of multiple SDG's (Duarte et al. 2021).

Fig. 6.2 Seaweed species have high range nutritional value and can be farmed with few environmental impacts and potential positive effects. (©TNC/Kevin Arnold)

However, despite high annual growth rates in seaweed production activity in seaweed aquaculture is largely nascent in many countries in the Pacific, including the larger industry jurisdictions of Australia and New Zealand (FAO 2020). Production is fragmented across the region, and farming has come up against multiple regulatory, technology, and social barriers. Recent work in the region has identified that actively linking seaweed production and processing to broader social, economic, and environmental goals could be an important pathway to overcoming current production and processing constraints, and building domestic demand and investing in the development of effective local supply chains could be an effective platform for then further growth (Paul 2020). Importantly, despite its nascent status in current production consumption of seaweed is not a new trend. In some Pacific nations seaweeds have cultural significance and are commonly consumed (Tiitii et al. 2022), but capitalizing on the potential for these species to be a nutritionally valuable and environmentally positive source of food will require an evolution from subsistence patterns of consumption to more widespread use (Butcher et al. 2020). Attention will need to be given to differences in local preferences (Butcher et al. 2020) and the production systems that are acceptable and most effective within jurisdictions (Paul 2020).

6.4 Conclusion

Safeguarding the health of fresh and marine water resources and systems will have benefits to the productivity and quality of food systems, as well as the water systems themselves. Without clean freshwater and sanitation, and intact, functioning marine environments, communities will experience ongoing impacts to health and wellbeing and increasing pressure on resources, because of population growth, competing needs for resources and economic opportunities (e.g. tourism), and climate change. The intrinsic connectivity of water and food provides an important opportunity to design and implement locally contextualized solutions, which can be assisted by thinking about their interdependencies and leveraging approaches that work at the nexus, such as IM, ridge to reef investment, NbS and regenerative practices. Central to this opportunity is the interconnectedness of people, place, and ecosystems in the Pacific. Ensuring Indigenous and local knowledge is included as an integral part of these solutions will be critical to their success (e.g. knowledge to optimize freshwater resource use during periods of acute water scarcity; MacDonald et al. 2020). In some nations and areas, local knowledge is driving the development of original solutions at the forefront of proactive responses, for instance the reinvigoration of traditional and agroecological methods for networked marine protected areas (Mcleod et al. 2019). In other nations, Indigenous and local knowledge is being overlooked in favour of technology innovation. Viewing the water-food equation as an opportunity to leverage connectivity and approach trade-offs, rather than viewing this connectivity solely as a challenge—often a highly complex challenge—provides a much-needed lens through which solutions that can improve the sustainability and resilience of ecosystems as well as communities can be developed.

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