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Review

A Review on Biodiversity, Ecosystem Services, and Perceptions of New Zealand's Mangroves: Can We Make Informed Decisions about Their Removal?

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Abstract: Mangrove cover is increasing in estuaries and harbours in many areas on North Island, New Zealand. The expansion of mangroves has been attributed to anthropogenic land-use change, including urbanisation and conversion of land to agriculture. Rapid expansion of mangroves in the coastal landscape has created discord in local communities over their importance in terms of the services they deliver to both wildlife and people. Some community groups have been advocates for the large-scale removal of mangrove habitat, whilst other local residents oppose this removal. This review paper investigated and discussed pertinent biodiversity and ecosystem services studies based in New Zealand mangroves from 1950 to 2017. Results showed that the majority of biodiversity studies have targeted particular species or groups of organisms, with a focus on benthic invertebrate communities. Deficits remain in our knowledge of this expanding forest and shrub ecosystem, notably the terrestrial component of biodiversity, species community-shifts with landscape fragmentation, and associated cultural values. It is recommended that broader species assessments and a longer-term approach be applied to biodiversity monitoring in mangroves, coupled with Mātauranga Māori (Māori knowledge) and western science for holistic management of this coastal ecosystem.

Keywords: mangrove; New Zealand; iwi; Māori; communities; biodiversity; ecosystem services; management

1. Introduction

The biosphere's ability to provide goods and services to support human populations is being severely compromised by rapid environmental change through the anthropogenic impact upon natural ecosystems [1]. Integration of natural and social sciences in order to address complex human-environment interactions has been slowly materialising over time [2]. However, studies integrating biodiversity monitoring and ecosystem services of natural ecosystems are few in number [3]. This paper reviews biodiversity studies and ecosystem services (defined as attributes) within mangroves, as natural systems under pressure from the anthropogenic impact. The specific focus of this contribution is on temperate mangroves in New Zealand. Within this body of literature, we explore linkages between (1) biodiversity; (2) ecosystem services; and (3) management of New Zealand's mangroves, and address the following broad-scale questions:

1. What biodiversity and ecosystem service information exists on New Zealand's mangroves?
2. What are the knowledge gaps in terms of potential species and ecosystem services occupying New Zealand mangroves?

3. How can we better integrate data for comprehensive and effective management decisions regarding the removal and preservation of these ecosystems?

1.1. Mangrove Ecosystems

Mangroves are forest ecosystems consisting of trees, shrubs, and ferns [4] occupying the intertidal zone between the land and sea. There are 73 species of 'true' mangrove and they are mainly located in the tropics and subtropics, ranging between 32° N and 38° S [5]. Mangrove latitudinal limits are primarily controlled by climate [6]. Globally, there have been significant losses in mangrove areas over the past fifty years [7]. Giri et al. (2010) estimated the total worldwide mangrove area to be 137,760 km^2, representing a decrease of 35% of the total area from 1980 to 2000 [8]. A further 1920 km^2 were lost between 2001 and 2012. Asia, specifically South-East Asia, contains the largest remaining mangrove area and has suffered the greatest losses, with more than 1000 km^2 lost between 2000 and 2012. The conversion of mangrove forests to aquaculture ponds accounted for 30% of the reduction in the mangrove area. Rice-agriculture expansion and palm oil plantations are also significant drivers for mangrove removal in South-East Asia [9]. In addition to aquaculture and agricultural land conversion, other significant drivers of global mangrove loss are increased urban expansion in coastal areas and infrastructure (resorts) to support coastal tourism development [10].

1.2. Mangroves, Biodiversity, and Ecosystem Services

Biodiversity or biological diversity refers to "the variability among living organisms from all sources, including, inter-alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" [11]. Loss of biodiversity from natural ecosystems can detrimentally affect both humans and nature [12].

Ecosystem services are the contributions to human welfare made by the natural world [13] (p. 246) and can be divided into three main categories: regulating, provisioning, and cultural, with supporting services underpinning the others [8]. The ecosystem services which mangroves provide in the tropics and sub-tropics are widely-recognised [14–16] and considerable emphasis has been placed upon assessing the value of mangrove ecosystem services using environmental economics [7,8,10].

Understanding the relationships between people and nature using an anthropocentric, specifically economic, perspective can be both insightful and valuable [17] (p. 13). Table 1 shows ecosystem goods and services of mangroves with their ecological function and direct, indirect, and non-use values [8,18,19].

Table 1. Services, function, and value types of economic goods and services of mangrove ecosystems. Direct use values correspond to physical interaction with mangroves by humans (provisioning services), which result in both consumptive and non-consumptive uses [18]. Indirect use values relate to regulating services, while non-use or passive values relate to cultural services [18]. Adapted from [19], with modifications from [8,18].

Ecosystem Service	Ecological Function	Economic Goods and Service	Value Type
Provisioning	Nursery and habitat for animal and plant species	Commercial & recreational fishing and hunting. Harvesting of natural materials, energy resources	Direct use
Cultural	-	Recreation, ecotourism Existence, bequest and option values	Direct use Non-use
Regulating	Carbon sequestration	Reduced global warming	Indirect use
-	Flood and water flow control, storm buffering, sediment retention, water quality maintenance/ nutrient retention	Flood and storm protection, improved water quality and waste disposal	Indirect use

1.3. Temperate Mangroves

The ways in which temperate and tropical mangroves are utilised by local communities are different [20]. Tropical mangroves exist mainly in developing countries (e.g., India, Thailand, Vietnam, Kenya, and Tanzania). In these countries, subsistence living and local livelihoods are closely linked to the utilisation of local environments. This creates co-dependency and potential for Payments for Ecosystem Services (PES) programs, in addition to incentives for the restoration and conservation of mangrove ecosystems [13] (p. 248). Temperate mangroves are generally located in the developed world where dependency on mangrove goods and direct services are much less important to communities, thereby affecting the value we place upon such ecosystems. Temperate mangroves occur in parts of the USA, Southern Brazil, South Africa, Japan, Australia, and New Zealand [20]. Of the six countries where temperate mangroves are located, four are in the top fifty GDP per capita (USA, Australia, New Zealand, and Japan) [21].

1.3.1. New Zealand's Mangroves

Mangroves are part of the indigenous flora of Aotearoa (New Zealand) and have been part of the natural environment for approximately 19 million years [22]. They are the most southerly growing mangrove ecosystem in the world. The only existing mangrove species in New Zealand is *Avicennia marina* subsp. *australasica*, which has existed there for over 11,000 years [23] and currently occupies an area of approximately 177 km^2 (data compiled [24,25]). Mangroves range from Cape Reinga in the far North of Northland, to Ohiwa harbour in the Bay of Plenty, on the East Coast and Kawhia harbour on the West coast [26–28] (Figure 1). Prior to the definition of ecosystem services, both Kūchler (1972) and Dingwall (1984) recognised that there was no direct utilisation of New Zealand's temperate mangrove for fuelwood, charcoal, or timber [29,30]. Historically, mangroves or mānawa had previous provisioning services for Māori. They were utilised for their tanning properties, as tools for pounding fern-root, and as dyes for clothes. Post-colonisation, boat-builders used green mangrove wood for shaping the stern and bow [31] (p. 23).

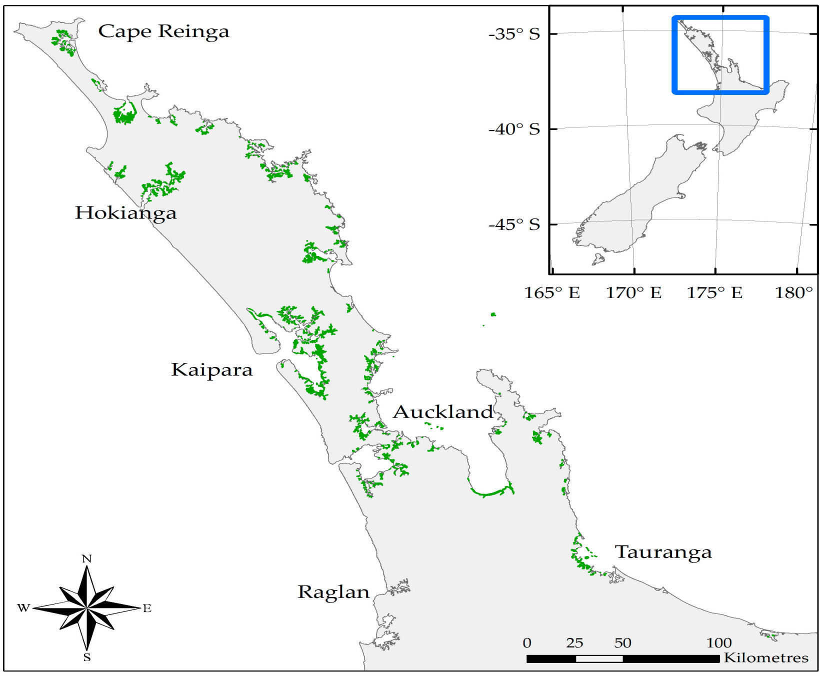

Figure 1. Map of mangrove distribution in New Zealand (green polygons) (Southerly limits below Tauranga). Adapted from [27,28].

Mangroves also provide a habitat for species utilised as seafood or kaimoana, such as parore (black fish; *Girella tricuspidata*), tio (Pacific and Rock oysters; *Saccostrea glomerata* and *Crassostrea glomerulata*), kanae (grey mullet; *Mugil cephalus*), and tuna (eels; *Anguillidae* spp.) for the local community of Motuti in Panguru, Hokianga, Northland [31] (p. 23). Even though the traditional uses of mangroves are not practiced, they still support both traditional Māori, community, and ecological values [32]. Current harvesting of tio by iwi and hapu (Māori tribes and smaller descent groups) occurs in the pneumatophore (aerial roots) zone of mangroves (seaward fringe), as far South as Tauranga. Previously, iwi in this area advocated for mangrove removal. Recently, however, a pro-protection attitude has been adopted by local iwi from the belief that the mangrove fringe in this area supports high abundances of tio [33].

1.3.2. Conservation Status and Policy: Treaty of Waitangi and the Resource Management Act

Te Tiriti o Waitangi or Māori version of the Treaty of Waitangi is one of New Zealand's founding documents signed on 6 February 1840 [34]. In this agreement, tribal proprietary rights over 'taonga' (e.g., traditional language, knowledge and customs, land, water, flora, and fauna) are guaranteed as 'te tino rangatiratanga' in Te Tiriti o Waitangi (Article 2). Despite this historic agreement, current legislation does not support Māori proprietary rights over flora and fauna, including mangrove. However, the Resource Management Act (1991) does make provisions for Māori consultation and decision-making over taonga, including mangrove management. The Wai 262 Report (flora and fauna section) also addresses 'ownership' and appropriation of Māori knowledge, customs, and cultural expressions surrounding indigenous flora and fauna, including all products derived from indigenous species [35].

Mangrove forests in New Zealand are protected from reclamation and indiscriminate destruction under the Resource Management Act (RMA) 1991 [36]. The RMA promotes sustainable management of physical and natural resources (e.g., land, air and water; [36]). In this context, sustainable management refers to "managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while—

sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and

safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and

avoiding, remedying, or mitigating any adverse effects of activities on the environment. ([36], Part 2, Section 5)

Despite the RMA, there is no clear mandate for mangrove conservation in New Zealand. Each regional council has their own policies and plans which relate to mangrove management. The Auckland Unitary Plan states that mangroves may be removed from the following areas; (i) the general coastal marine zone; (ii) significant ecological areas where ecosystem service values are not from mangroves and (iii) significant ecological areas that are wading bird habitats (if they did not exist in these areas prior to 1996). (This was the earliest year where comprehensive aerial photography existed for the Coastal Marine Area (CMA) in the Auckland region) [37]. In order to effectively achieve the goals of the RMA, any persons managing natural and physical resources must take into account the Treaty of Waitangi (Te Tiriti o Waitangi), 1840.

The Treaty provides a framework for engagement and partnership between Māori and the government. Although there has been controversy and disagreement over the treaty since 1840, the Principles of the Treaty itself provide a strong framework for decision-making between Māori and the crown, as well as other stakeholders regarding the environment [38]. Under central and regional government policy, iwi are recognised as kaitiaki (or guardians) and decision-making partners with customary rights. Therefore, iwi should be involved at the start of any decision-making process regarding natural and physical resource management. Overall, current resource planning has failed to fully account for rights and interests of Māori, mainly due to the mainstreaming of planning concepts, which originate from Western cultural concepts [39,40].

1.3.3. Mangrove Expansion and Removal

Over the past 150 years, mangrove expansion within estuaries has occurred due to increased sedimentation rates caused by changes in land-use, linked to urban and industrial development and agriculture [26,41]. Increased soil erosion in the wider catchment area and accelerated estuary infilling has led to the expansion of mangroves at a mean rate of 4% per year across New Zealand [26]. This expansion has created local estuarine management issues and polarity in public attitudes towards their conservation [20,32,41–43].

There is a perception amongst some communities that mangrove expansion has a negative impact on the surrounding estuarine environment and reduces recreational and amenity values of coastal communities [44,45]. Boat and fishing access and vistas of the estuary and open water have been identified as important drivers for mangrove management and subsequent removal in New Zealand [42].

Regional councils have come under pressure from local community groups campaigning for the removal of large areas of mangroves [44], leading to a number of resource consents being granted by regional councils to remove large areas of mangrove habitat from estuarine environments [46], following an Assessment of Environmental Effects [26,36]. Mangrove removal may detrimentally affect the surrounding estuarine and wider environment in many ways, including declines in water quality through the release of contaminants and sediments into waterways. Habitat loss for a variety of species will occur with mangrove removal, in addition to compromising the role of mangroves as carbon sinks and buffers against floods and storms [26,47,48].

In New Zealand, there is a strong focus on using citizen science for data collection, especially in the monitoring of biodiversity [49]. Incorporating Mātauranga Māori with environmental monitoring in community groups which are undertaking restoration projects (grassroots citizen science) is now being used in order to address socio-cultural needs and wishes [50]. Estuary Care Groups have formed across New Zealand in order to 'maintain estuary values' [51]. Mangroves play an integral role in this monitoring due to their expansion. The National Institute for Water and Atmospheric Research (NIWA) has created guidelines for the community-focused ecological monitoring of mangroves, in conjunction with Waikaraka Estuary Managers [52]. The Bay of Plenty Regional Council have also created an environmental monitoring tool kit for estuary care groups to better understand ecosystem recovery and support future consents of mangrove removal [51].

How ecosystem services are affected by the removal of mangroves has not been investigated in detail in New Zealand. Due to the increasing number of mangrove removals and lack of information on the impact this is having on the ecology of the areas, there is a pressing need to understand drivers for differing attitudes and perceptions towards mangroves and how these perceptions influence management decisions. Perception in this context can be thought of as the awareness an individual has towards something because of their practical interrelationships with nature on a daily basis ([53], p. 24). There is a strong pro-removal attitude in New Zealand towards mangroves, which directly influences management decisions. Decisions for large-scale removal will affect the biodiversity of remaining mangrove patches and the surrounding coastal landscape [42,44,46].

2. Materials and Methods

In this paper, we undertook a thorough review of published, peer-reviewed literature, in addition to documenting regional council reports (available online), about New Zealand mangrove ecology and management. This paper looks to build upon the review about the ecology and management of New Zealand's mangroves by Morrisey et al. [20]. Our results and discussion summarise all peer-reviewed published studies and key reports (from 1950), with a strong focus on new research carried out in terms of biodiversity, ecosystem services, and economic valuation of mangroves in New Zealand (post 2010). Studies were divided into categories of biomass/abundance/distribution, nutrients, sedimentation, economic valuation, cultural value, and management of mangroves. Management papers were also reviewed in order to integrate current knowledge and identify gaps in information with recommendations going forward.

The literature search was conducted using the search terms "mangrove*" and "New Zealand" with the search engines Web of Science, Web of Knowledge, and Google Scholar. Search terms were intentionally left broad so as to encompass all published peer-reviewed studies and council reports over the time period between January 1950 and July 2017. Whole papers were read, with the title, location of study, results, and references extracted. Papers and reports were categorised into biodiversity studies or mangrove attributes Results are presented for each field of study and by location and year, with the aim of highlighting knowledge gaps in both ecological and societal connections with mangroves.

3. Results

Seventy-seven papers were identified from the literature (1952 to July 2017). Overall trends (with the exception of the 1960's) show an increase in number and type of study per decade (Figure 2). Biodiversity studies represent the majority per decade (with the exception of the 1950's, where biomass/abundance/distribution papers are slightly higher).

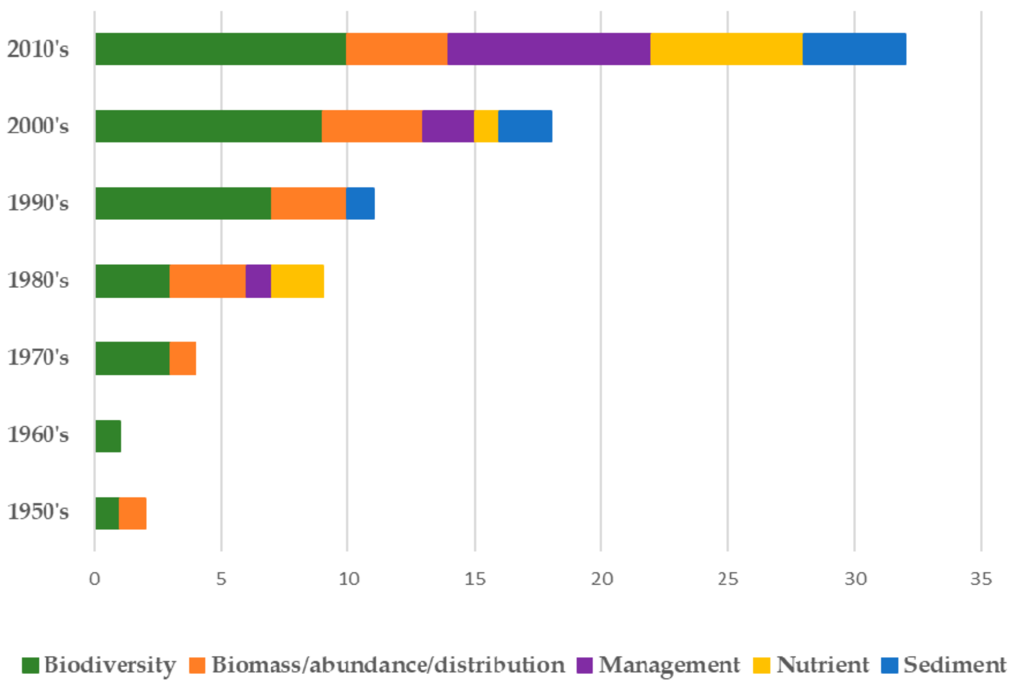

Figure 2. Studies on New Zealand mangrove attribute by decade up to and including 2017 (n = 77). Studies identified from the literature were grouped into five categories of "biodiversity", "biomass/abundance/distribution", "management", "nutrient" and "sediment" papers and then by decade to document changes over time [20,26,29–31,33,43,44,46,54–131].

3.1. Biodiversity

A total of thirty-five peer-reviewed studies were classified as biodiversity in mangroves (Figure 3), including one technical report on the impact of the removal of mangroves on benthic communities conducted by NIWA on behalf of Auckland Council [46]. The majority of studies have occurred in the past two decades, dominated by microbenthic invertebrate studies (37%), followed by birds and insects and spiders (both 23% of total studies), 8% of peer-reviewed studies are around fish, 6% are on mammals, and one single study is on lichens in mangroves.

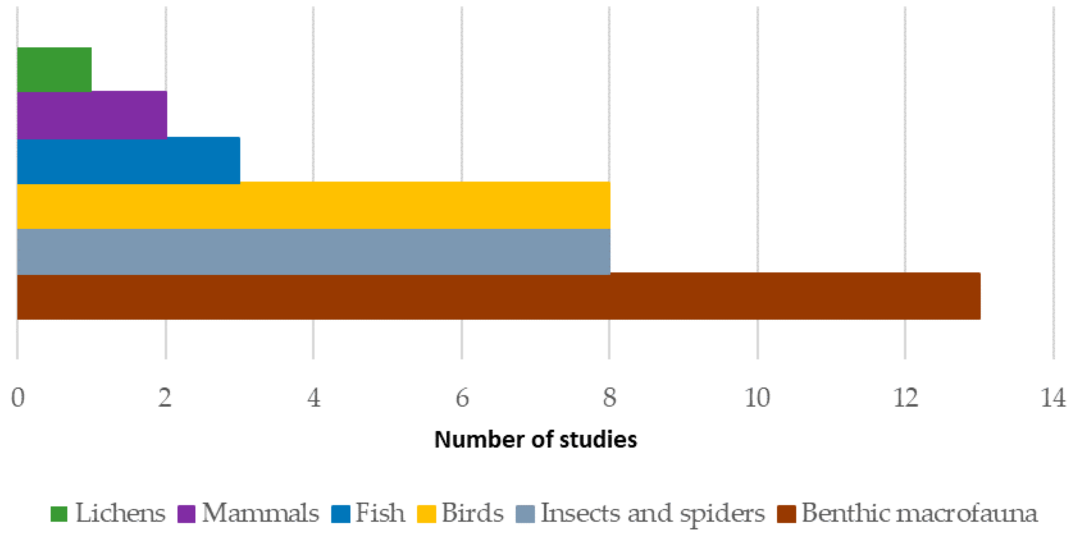

Figure 3. Online published biodiversity studies in New Zealand mangrove (peer-reviewed and technical reports from councils (1950–2017, n = 35)). Studies were quantified and separated into type of organism [26,31,43,46,54–72,84,90–101].

3.1.1. Macrobenthic Invertebrate Studies

Recent studies (2003–2017) have indicated a lower macrobenthic invertebrate abundance associated with mangrove habitat compared to adjacent unvegetated habitats [43,54,55], with mature stands of mangrove showing the lowest diversity [55] and a greater number of taxa and abundance in young mangrove stands [56]. Focus on the effects of mangrove removal on macrobenthic invertebrate communities has risen over the past decade, to observe whether communities in removed areas are similar to those of mudflat communities over time. Bulmer et al. (2017) showed that the removal method had an effect on the reversion of benthic community structure to previous sandflat communities. Hand clearances, sites exposed to greater hydrodynamic forces, and the removal of above-ground biomass showed the highest chance of transition to an adjacent sandflat habitat, although this was unlikely to occur in the first five years after removal [57]. Stokes (2010) observed a low diversity of gastropods, polychaetes, and decapods in both mudflats and mangroves at three sites in Tauranga Harbour post-removal, with an absence of bivalves at both habitats [58]. A shift from filter-feeding to deposit-feeding communities occurred at these sites, which was driven by increased sedimentation and finer sediments within the upper estuaries [58].

There is a considerable amount of variability in the responses of macrobenthic invertebrate communities with mangrove removal. A study on the effects of different methods of mangrove removal on benthic invertebrate communities was carried out at nine locations (twenty plots) in the Auckland region [46]. Mechanical removal, with biomass left in situ, showed less recovery towards sandy habitats and corresponding macrofaunal invertebrate communities. Smaller clearings, using non-mechanical methods with biomass removed, were more likely to recover in the direction of macrofaunal invertebrate communities associated with sandy habitats. Seaward edges were more likely to show recovery than centre or landward edges of mangrove removal areas, as exhibited by the increasing diversity of benthic invertebrate species from the centre to the edge of unvegetated areas [46]. Macrobenthic invertebrate studies dominate the literature of mangrove biodiversity in New Zealand. Benthic macrofaunal invertebrates respond in a variety of ways depending on the mangrove removal method, location of area removed, and the hydrodynamics of the area [46,57,58]. Mature mangrove supports lower macrobenthic invertebrate diversity and abundance than young mangrove and adjacent mudflats [43,54–58].

3.1.2. Birds

Assessments of birds inhabiting mangroves are sparse, with the most comprehensive assessment by Cox (1977). Twenty-two species of birds were observed and recorded in mangroves at specific sites in Kaipara Harbour, eleven of which showed signs of regular usage [59]. A native bird species known to frequent mangroves is the Banded Rail (*Gallirallus philippensis*). Recent work on Banded Rail in Mangawhai mangroves has shown their presence within the mangrove and at the edges, with an increase in foraging behaviour on the outer edges (seaward fringe) [132]. Two studies have been published on the nationally threatened New Zealand Fairy Tern *Sternula nereis davisae* or tara-iti in the mangrove [60,61] in Mangawhai and Kaipara, respectively. Baird et al. (2013) observed Fairy Tern sightings in Kaipara mangroves and Ismar et al. (2014) identified the mangrove-lined highly tidal and shallow mid-estuary and the lagoon on the sand spit as foraging hotspots for breeding populations in Mangawhai. More research is required on birds occupying New Zealand mangroves, including long-term monitoring of populations of Fairy terns and Banded Rails.

3.1.3. Insects and Spiders

There have been eight peer-reviewed published studies on insects and spiders, including single species studies on the endemic obligate tortricid moth (*Planotortrix avicenniae*) [62] and the eriophyid mite (*Aceria avicenniae*) [63]. Other studies include the presence of the Asian paper wasp (*Aceria avicenniae*) [64], the scale insect (*Ceroplastes sinensis*) [65], invasive argentine ants (*Linepthima humile*) [66], and the painted apple moth (*Teia anartoides*) [67].

Personal communication from Dugdale in Morrisey et al. (2010) listed the lemon-tree borer beetle (*Oemona hirta*) and ant colonies within tunnels of mangrove stems made by boring insects. In recent years, one study on the diversity of arthropod communities in Firth of Thames mangroves identified 101 species, 44% of which had not been found in any other inland habitat. The author concluded that the terrestrial arthropod community in this area was unique compared to other New Zealand habitats and may include species not present elsewhere [68]. The studies on terrestrial invertebrates in New Zealand mangroves are few in number. It is imperative that more information is documented on terrestrial invertebrate populations in mangroves.

3.1.4. Fish

Ritchie (1976) identified 30 species of fish which regularly occupy mangroves, including flounder, mullet, and eels as permanent residents; snapper, trevally, baracouta, and mackerel being frequent visitors; and dogfish, shark, and red moki occasional users [69]. A broad-scale study by Morrison et al. sampled mangroves bordering eight estuaries between February–April 2006 [26]. Nineteen species were recorded, dominated by yellow-eyed mullet *Aldrichetta forsteri* (65.5%), and grey mullet *Mugil cephalus* (17.9%). Short-finned eels were positively related to the habitat complexity of mangroves [26]. However, no comparisons were made with adjacent habitats, therefore the importance of mangrove habitat and potential nursery roles could not be assumed.

Further research is being conducted following Morrison et al. (2010) to understand the habitat use of mangroves by fish as explained below from personal communication with Mark Morrison (2017). There are three species that can be defined as using mangroves as a fisheries habitat, defined as using this habitat disproportionately more than other habitats. On the East Coast, mangroves are a habitat for juvenile parore, on the West Coast they are a habitat for grey mullet juveniles and short-finned eels on both coasts [133].

It is possible that the expansion of mangroves in these areas may mitigate against the loss of freshwater habitats for the short-finned eel. However, there are no estimates for this. There were large numbers of very small grey mullet exiting the mangroves in the Manukau as the tide dropped when it was sampled, and it is suspected that they use mangroves here to avoid predation [133]. It is likely that the quality of food or amounts of food for mullet are much less in mangroves than intertidal mudflats, which is possibly driving that reduction in growth rate [133].

A recent study conducted by Lowe (2013) found grey mullet and pilchard in high abundance in Manukau harbour and Mahurangi, respectively. Diversity and abundance of fish species were greatest in seagrass, followed by sandflats, mangroves, and mudflats [70].

Comparisons of fish utilisation between mangrove and adjacent coastal ecosystems are required before we can understand the value of mangrove habitats to different fish species.

3.1.5. Mammals

Two studies have been published on the presence of mammals in New Zealand mangroves to date. Cox (1977) observed rat droppings and footprints at a Kaipara mangrove site and Blom (1992) speaks of the presence of weasels (*Mustela nivalis*) in mangroves ([59,73], respectively). Morrisey et al. (2010) stated that it is likely that the brush-tailed possum *(Trichosurus vulpecula)* uses mangroves due to its ubiquitous nature in New Zealand. A current study (in progress) looking at mammalian predators in Mangawhai mangroves using camera traps found rats present at the outer edge and interior of the mangrove, along with rats, cats, stoats, hedgehog, and ferret footprints at the saltmarsh/mangrove fringe [132]. There is limited knowledge on the presence of mammals in mangroves in New Zealand; studies have identified non-native, invasive mammalian species as occupying mangroves [59,71,132].

3.1.6. Lichens

A recent study has been published regarding the presence of lichen on mangroves [72]. The authors, sampling 200 trees from 20 mangroves sites throughout North Island, documented 106 lichen species from 45 genera, which were correlated with diameter at breast height of mangrove and mean annual rainfall. Two 'Nationally Endangered', five 'Naturally Uncommon', and twenty-seven 'Data Deficient' species were identified, highlighting the importance of mangroves for lichen species. Comparable numbers of lichens have also been found in both tropical and sub-tropical mangroves globally [72]. This recent study is currently the only published peer-reviewed paper on lichens in mangroves in New Zealand. It is important for the monitoring of threatened lichen species to continue as part of mangrove biodiversity knowledge in the future.

3.2. Attributes-Regulating and Supporting Service Studies

Research involving regulating and supporting services of mangroves was identified in thirty-two peer-reviewed published papers, with 50% from the last seven years. A strong focus of these recent papers has been on macronutrients (carbon and nitrogen) in mangrove leaves, below-ground biomass (roots), and sediment.

3.2.1. Nutrients

Gritcan et al. (2016) investigated levels of nitrogen and phosphorus in mangrove leaves in Mangawhai, Waitemata, and Manukau. Results showed significant differences among the areas, with Mangawhai having lower levels of total nitrogen and δ^{15} nitrogen than Manukau (2.2%N and 9.9‰ and 2.0%N and 5.2‰, respectively) and Waitemata having intermediate levels. A decrease in leaf total nitrogen and δ^{15} N in Waitemata mangroves over the past 100 years was also documented. This suggests a decline in anthropogenically derived nitrogen inputs, which may be linked to sewerage system improvements in the harbour over the same period [73].

A few studies in recent years have focused on the carbon allocation of mangroves in above-ground biomass (AGB), below-ground biomass, and sediment carbon stocks. Allometric equations were produced for AGB, carbon, and nitrogen stocks at the southerly distribution of *Avicennia marina australasica* in New Zealand by Bulmer et al., (2016a). Results showed that carbon and nitrogen stocks accounted for $41.23 \pm 0.40\%$ and $1.28 \pm 0.03\%$, respectively, of total above ground biomass. Tree canopy volume was the greatest predictor of all three variables [74].

Tran et al. (2016) also looked at carbon allocation in *Avicennia* at Mangawhai and estimated that New Zealand mangroves stored a total of 0.2–1.1 Mt carbon (C) in above-ground and 1.06–1.72 Mt C in below-ground biomass [75]. Carbon and nitrogen stocks in below-ground biomass and sediment were also measured at five mangrove sites across North Island [76]. Results showed that carbon contributed 88 ± 3% of total below ground stocks, and nitrogen contributed 99 ± 0.4% of total stocks.

Sedimentary carbon stocks were affected by mangrove removal, as shown by a recent study by Perez et al., (2017). The authors looked at the effects of mangrove removal on the amounts of sediment carbon in Whangamata and found that removed sites of mangroves showed a marked decrease in sedimentary carbon stocks (2767 ± 580 g m^{-2}) in comparison to the preserved area (6949 ± 84 g m^{-2}) [77], which was coupled with a decrease in sedimentation rates in removed areas. Total organic carbon concentrations were also markedly higher in areas dominated by mangroves (post 1944) in comparison to areas dominated by salt marshes (pre 1944) [77].

Rates of efflux of CO_2 have also been compared between cleared and intact mangroves in a recent study [78]. Sediment CO_2 efflux rates were 168.5 ± 45.8 mmol m^{-2} d^{-1} and 133.9 ± 37.2 mmol m^{-2} d^{-1} from cleared mangrove forests [78]. The authors stated that these rates are comparable to rates from tropical mangrove forests. These studies showed the importance of mangroves as nutrient sinks, especially for carbon storage.

3.2.2. Sediment Accumulation

There has been an increase in the number of papers addressing sediment accumulation rates in the past few years. Of notable interest are three papers around the projected responses of mangrove ecosystems to sea-level rise in New Zealand [79–81]. Results showed that the fate of mangroves depends on sediment elevation rates keeping up with relative sea-level rise [79]. Current or increasing sediment supply will allow for the maintenance or expansion of mangrove habitats. A rapid increase in mangrove expansion is only likely to occur in smaller estuaries with a high sediment load and limited flushing [79]. A reduced supply of sediment will result in a large decrease in mangrove upper zones [81].

3.2.3. Biomass/Abundance/Distribution

Many studies have examined the expanding distribution of mangroves over time, from Chapman and Ronaldson's work on mangrove and salt-marsh flats of the Auckland Isthmus in 1958 [82], up to the present day (2018). Focus has shifted to the quantification of carbon stores and comparisons with tropical mangroves and adjacent habitats such as seagrass. A recent study of interest compared digital images of mangrove on Motu Manawa, or Pollen Island, from 1940 to 2003, finding an increase in mangrove area of 21% [83]. This expansion was linked to sediment retention and an increase in total organic carbon, with accumulation occuring in the interior of the mangrove as it expanded seaward [83].

A recent litter production and decomposition study in Whangamata mangroves showed that leaf litter decomposition is an order of magnitude slower than that of tropical mangroves [84]. Litter fall within the forest (older trees) was significantly higher (t-test, $p < 0.05$) than that of younger trees on the edge of the forest, with roughly half of the production. The authors concluded that mangrove detrital production was comparable to seagrass (*Zostera muelleri*) in the Whangamata Harbour [84]. These studies showed that mature mangroves have high levels of total organic carbon and high detrital litter production.

3.3. Attributes-Social and Economic Studies

Eleven papers addressed social (cultural and management) and economic studies in mangroves, with the majority (ten) having been published in the past decade. The proliferation of management papers has coincided with the increase in removals, which have used a variety of removal techniques.

3.3.1. Management

Two general management papers published in recent years highlight the main reasons behind removal. These include a desire to revert mangrove habitats to sandflats existing before mangrove colonisation in the 1950's and to increase the recreational and amenity value of open-water spaces, including cultural waka (canoe) access [85].

Other reasons for removal include restoration of seagrass and shellfish beds, improved functioning of drainage systems and increased flood protection [86].

A study of 40 removal sites indicated the likelihood of reversion to sandflats following removal is rare, often having detrimental effects on the local ecosystem and amenity (sights and smells) instead. Methods of removal impact upon the reversion of the areas to previous sandflats, in addition to wave action and tidal flushing. The authors suggested the following for effective management: If removal of the mangrove is to go ahead, seedling removal provides a low impact method of management. However, seedling removal will be continuous due to rapid colonization or Srecolonization of mangroves. This method will remove additional growth, but not the established mangrove.

Mechanical removal creates the most physical disturbance and compression of the seabed, in addition to anoxic conditions created by mulch left in-situ, smothering benthic communities [42,86]. Smaller areas of mangrove removal recover faster and it is recommended that small strips of mangrove are removed on the seaward boundary of a mangrove stand in order to maximise exposure to wave action and tidal flushing [86]. The authors also highlighted the importance of baseline monitoring pre-removal and comparisons with post-removal data to be made in order to evaluate the achievement of removal objectives and to provide an indication of the ecological health of the area [86]. Mangrove management is a complex topic to be addressed on a site-by-site basis; it is not a one-case-fits-all issue [85,86]. Mangrove removal of large areas is not advised before long-term ecological monitoring of a coastal area has been undertaken [86].

Table 2 summarises social and economic studies on New Zealand mangroves between 2013 and 2017.

Table 2. Recent management papers on mangroves in New Zealand, categorised by type of paper (E = Economic Valuation, C = Cultural Impact Assessment, M = Management), topic, location in New Zealand, general notes, and references (2013–2017).

Type	Topic	Location	Notes	Ref.
E	Costs of removal	Auckland and Tauranga	Variation of costs ranging from $10,000–$33,000 NZD/Ha for removal	[111]
E	Total economic value of land-based ecosystems	New Zealand-wide	Gross value of $144,000,000 NZD for mangroves	[88]
E	Cost-benefit analysis of managing mangroves	Auckland	Projected expenditure 2011 local board plans including mangrove removal	[87]
C	Cultural impacts of mangrove removal	Auckland	Restoration of mauri of harbour is of most importance	[89]
M	Management and Planning review	Tauranga	Harbour-wide management of mangroves difficult to achieve. Need site-specific assessments.	[111]
M	Managing mangrove expansion	New Zealand-wide	Likelihood of successful restoration rarely considered, minimal information on long-term trends in ecosystem health of removed areas	[85]
M	Management guidelines	General New Zealand	Land-use to reduce sediment loads needs to be better managed, pre-removal baseline data required	[86]

3.3.2. Economic Valuation and Cost of Removal

Costs of mangrove removal vary by method, area, and timeframe. Auckland Council (2015) provided a list of estimated costs for removals in the Auckland and Bay of Plenty regions. The resource consent costs ranged from $2500 NZD (Auckland Airport) to $38,000 NZD (notified and full hearing process, Pahurehure Inlet 2). Costs for removal ranged from $10,000 to $33,000 NZD per hectare with monitoring costs ranging from $10,000 for baseline, up to $15,000 for monitoring during and post- removal [83]. The largest resource consent for removal in the Auckland area to date was 27 hectares of mangrove in Pahurehure Inlet 2, between 2010 and 2012. This cost $1.5 million NZD [87]. Another current removal is in Waimahia (19.3 Ha). Costs are estimated at $880,000 NZD for removal, plus $28,000 for a works management plan and $5000 for a bird survey. Table 3 shows costs of removal for some of the largest areas in the Auckland region in recent years.

Table 3. Costs of consent process and removals of mangroves in Auckland region (selected recent examples of substantial areas of removal 2010–2017).

Region	Activity	Method	Year	Costs (NZD)	Ref.
Papakura Auckland	Mangrove and seedling removal over 3 years (27 Ha)	Tractor and helicopter to remove AGB, roots left in situ	2010–2012	$1,500,000	[87]
Waimahia	Mangrove and seedling removal	Handsaw, loppers	2015	$888,000 (works costs) plus 28 k works management plan and 5 k bird survey (projected)	[111]
Mangere and Waitemata	Consenting process and removal of mangroves in Auckland's two harbours	Hand removal	2011 Local Board Plans	$780,000	[87]

A nation-wide survey of the total economic value of New Zealand's land-based ecosystems and their services was conducted in 2013, by Patterson and Cole [88]. Results from this rapid assessment of land-based ecosystems valued mangroves as having the lowest net worth (Figure 4a), with a gross-value of $144 million NZD (2012). This covers the services of disturbance regulation (flood control, storm protection, and drought recovery) ($95 million NZD), refugia for wildlife (nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds) ($8 million NZD) and passive use value (non-use values) ($44 million NZD) [84]. When considering value per hectare, these figures (Figure 4b) place mangroves in sixth place in terms of the highest total use value ($5000 NZD/Ha).

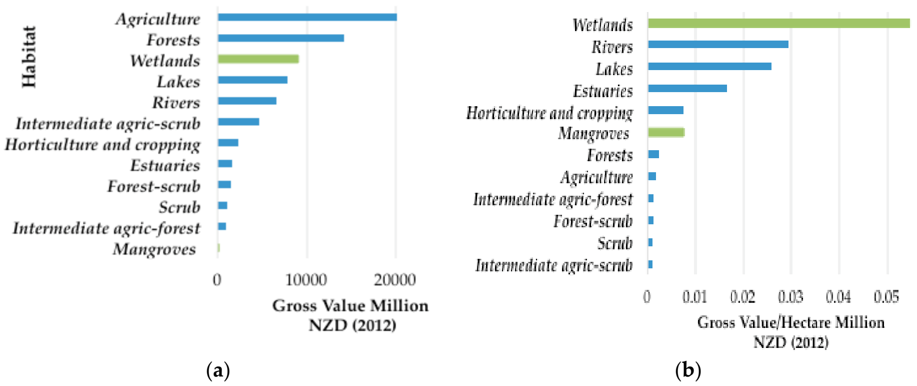

Figure 4. (**a**). Gross value (use value + passive value) estimated for New Zealand's land-based ecosystems in 2012 and (**b**) Gross value (per hectare) estimated for New Zealand's land-based ecosystems in 2012. Both (a) and (b) are adapted from data extracted from [88].

These studies highlight the expense involved in mangrove removal and the ambiguous information displayed regarding the valuation of mangroves in terms of the ecosystem services they provide (mangroves are separated from wetlands in this assessment). More comprehensive information is required to provide accurate estimations of the value of mangroves in New Zealand.

3.3.3. Cultural Studies

Only one published study mentions the cultural value of mangroves in New Zealand [88]. The authors stated that no reliable data could be found for ecosystem service valuation of mangroves and therefore, they placed provisioning and cultural values of mangrove as zero.

Ngāti Te Ata Waiohua (mana whenua of the Mangere-Ōtāhuhu area) carried out a cultural impact assessment in 2015 for Auckland Council for mangrove removal at sites around Mangere in the Manukau, Auckland. This impact assessment was written prior to approval of the resource consent for mangrove removal at four sites (Kiwi Esplanade, Norana Park, Hastie Avenue, and Mahunga Drive, totalling 13.5 Ha), providing an insight into the views of this iwi towards mangrove removal. Ngāti Te Ata Waiohua state that: "*We are not opposed to the removal of mangroves providing that the storm water and other source discharge are of the highest standard and that comprehensive, sufficient research is undertaken to justify their removal*". Overall, this Iwi's primary objective is to "*restore the mauri* (life-force) *of the harbour so it begins to heal itself*" [89]. Very little is known about the cultural value of mangrove to iwi. This is an area which should be explored further.

4. Discussion

Despite an increase in the number of studies covering a wide-range of mangrove ecosystem services, or attributes, there are still substantial knowledge gaps in our understanding of mangrove ecology in New Zealand. Of all biodiversity studies on mangrove in New Zealand, the focus and most knowledge gained has been around benthic macrofaunal invertebrate communities and comparisons with adjacent mudflat habitats. Given the ease of sampling and realtively straight-forward identification of species, this kind of monitoring gives fast and informative results. However, valuation of the mangrove habitat in terms of the abundance and diversity of organisms should not be based on these studies alone.

The role of mangroves in providing a habitat for terrestrial species, not just marine and freshwater organisms, has been largely overlooked globally [120,121]. Little information is available for terrestrial vertebrates, such as mammals, reptiles, and amphibians [120]. A recent global review of these groups in mangroves found 464 species of terrestrial vertebrates documented in mangroves worldwide [121].

No peer-reviewed published study has been carried out on the presence of reptiles in mangroves. Crisp et al. (1990) referred to Pacific and forest geckos (*Hoplodactylus pacificus* and *H. granulatus*, respectively) being found in northern mangroves (Hokianga and Rangaunu), as well as sea snakes (*Laticauda colubrina*, *L. laticordata*, and *Pelamis platurus*) (although these are rare). No citations were provided in these descriptions of reptiles [31] (p. 37).

Recently, there has been an increase in the use of camera traps or trail cameras in New Zealand mangroves. These have recorded the presence of mammalian predators, such as stoats, rats, hedgehogs, cats, and ferrets, as well as the Banded Rail in Mangawhai and Waitakere mangroves (a nationally declining bird species) [122,132]. Another mammal of interest for long-term monitoring is the long-tailed bat (*Chalinolobus tuberculatus*), but there are no records on the activity of this species over brackish water environments. High food availability (flying insects such as moths, beetles, mayflies, mosquitoes and midges) in mangrove areas is likely [122]. Long and short-tailed bats are New Zealand's only native land mammals [123]. Geckos and bats rely on insects as a food source.

Apart from one study on terrestrial arthropod communities in mangroves in the Firth of Thames [68], no other published study has assessed any form of insect diversity in New Zealand mangroves. A recent review exploring linkages between biodiversity attributes and ecosystem services across multiple natural ecosystems has shown a positive relationship between the two. For example, species level traits such as the abundance or number of species is important for pest regulation, pollination, and recreation [3]. Assessing biodiversity within mangrove ecosystems in New Zealand has not been investigated in any detail across groups of organisms. Establishing baseline data on the diversity, densities, and distribution of groups of organisms will contribute to ecological knowledge on mangroves and provide insights into linkages between species and the resulting ecosystem function in terms of biodiversity.

As well as an increase in the number of biodiversity studies in New Zealand mangroves, studies on macronutrients, such as carbon and nitrogen, in both above- and below-ground biomass and sediments are also on the rise. Globally, research on the role of mangroves as carbon sinks and mangrove sediment as a store of blue carbon is also underway [124–126]. Research in this field in New Zealand is beginning [74,76], in addition to studies on sea-level rise and how this may affect mangrove distribution in the future. These studies will provide important information for climate change adaptation and mitigation in New Zealand.

Knowledge gaps include the retention of contaminants in mangroves, such as transitional metals. Recent studies from New Caledonian mangroves showed that nickel, chromium, and iron concentrations were substantially higher in mangrove areas sampled than the global average in mangroves [127]. The role of mangroves in retaining transitional metals is related to the water quality of the surrounding environment and thus has both ecological and societal implications in terms of mangrove removal. The objective of all iwi is to restore the mauri, or vitality, of harbours and waterways. Understanding how mangrove removal affects the release of contaminants in the water should be a priority for research. Some kaitiaki (guardians of the environment) state that the removal of some areas of mangrove should be stopped until we have information on this [128]. This is an example of how Māori values and mātauranga can be integrated with ecological knowledge for the sustainable management of estuarine and coastal areas where mangroves are present. Figure 5 summarises ecosystem service studies and processes in New Zealand mangroves.

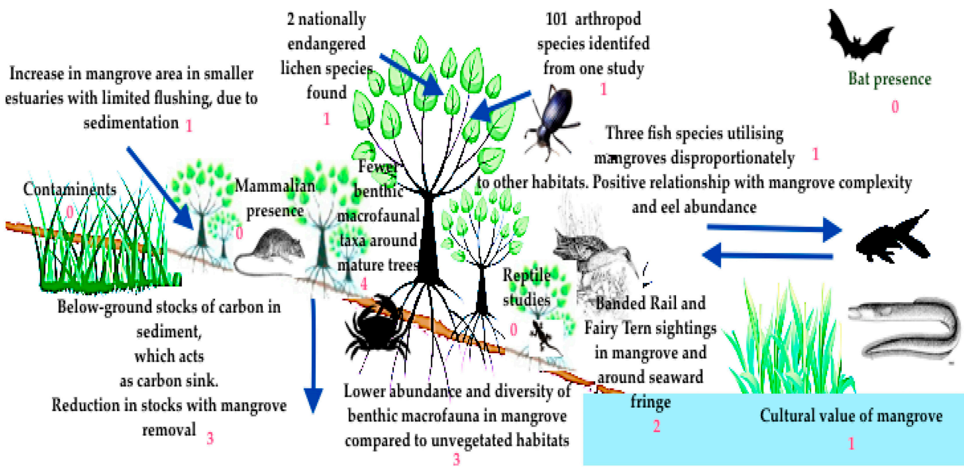

Figure 5. Pertinent biodiversity and mangrove attribute studies in New Zealand mangroves (2010–2017). Pink number refers to the number of studies since 2010 [26,43,54–58,60,61,68,72,77,79,134–141].

Economic studies have highlighted the high costs involved in removing mangroves. The costs of lodging a consent application, removal, disposal, and on-going ecological monitoring of a site need to be considered. Patterson & Cole (2013) estimated the value of mangroves in New Zealand based only on disturbance, refugia, and the passive value of mangroves in New Zealand. They also separate mangroves from wetlands in this study, when mangroves are in fact coastal wetlands [129]. The authors identified a lack of available information on the valuation of mangrove ecosystems in New Zealand.

The main influence on mangrove presence in New Zealand is human activity and related consents for removal, which is driven by a perception from some people that mangrove expansion has detrimentally affected the coastal and estuarine environment, replaced habitats for some species, and reduced recreational activities and amenity access. The lack of published data on perceptions and attitudes of local communities (iwi and other community groups), and the limited number of ecologists involved in monitoring these habitats, must be addressed. This will create an overall understanding and knowledge or mātauranga around socio-cultural and ecological values of mangroves at particular sites in New Zealand.

Mangrove management should not just be viewed in terms of seedling and young tree removal as sedimentation loads will allow for continued reestablishment of mangrove propagules in many regions. Wider land-use management addresses sediment loading in addition to finding a balance between maintaining ecosystem services of value and the wants and needs of local communities [86]. The link between mangrove ecosystems and local community aspirations is very strong in some estuaries and harbours in New Zealand where mangrove expansion has occurred rapidly. The system itself is a social-ecological system (SES) and therefore requires an SES framework, which incorporates both societal perceptions and attitudes along with ecological monitoring in order to address coastal sustainability. A mixed methods approach to collecting, analyzing, and evaluating social-ecological data to address mangrove management is recommended.

5. Conclusions

The range of attribute studies and subsequent findings highlight the complexity of mangrove management in New Zealand. A reductionist viewpoint towards biodiversity does not give recognition to how local people interact with and understand nature [130]. Indeed, the management of mangroves in New Zealand has been referred to as a 'wicked problem' as it has many causes and non-definitive solutions [87]. Currently, we cannot make informed decisions about mangrove removal due to the gaps in ecological and socio-cultural knowledge (including both traditional and current local ecological knowledge), which still exist. The interconnection between ecological and social systems must be considered if we are to address these complex interactions [131]. An integrated approach to overall estuarine and coastal management, which uses traditional ecological knowledge and engages iwi in long-term monitoring of these dynamic ecosystems, is the end goal.

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