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Fishes of Moreton Bay: Ecology, human impacts and conservation

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Abstract

Moreton Bay is a heterogeneous seascape containing a mosaic of habitats that support a diversity of fish. The fish fauna includes many species that are harvested by recreational and commercial fishers as well as numerous taxa that are of conservation concern. The fish fauna of mangroves, seagrasses, inshore reefs and intertidal flats is well sampled. By contrast, fish surveys in saltmarshes, soft sediments, offshore reefs and surf zones are sparse and incomplete. Fish diversity and abundance are typically highest on reefs and seagrass meadows, but most species move among habitats to feed and spawn. These movements connect habitats and link both fish assemblages and food webs across seascapes. The combined effects of water quality, coastal urbanisation and fishing also shape fish assemblages in Moreton Bay. Fish diversity and abundance increases from the urbanised western to the less developed eastern Bay. This spatial pattern mirrors gradients in water quality and habitat condition across the Bay. The shorelines of many estuaries and ocean beaches have been developed, and this coastal urbanisation has altered fish diversity, abundance and diet. Numerous species have, however, adapted to capitalise on the abundance of food and shelter in urban estuaries. No-take marine reserves prohibit fishing, and this promotes fish abundance and diversity in some ecosystems (e.g. coral reefs, seagrass meadows), but not in others (e.g. estuaries, ocean beaches). Important challenges for future research in Moreton Bay include: (i) testing how multiple human pressures combine to modify fish assemblages and fish habitats; (ii) identifying how the ecological attributes of ecosystems and seascapes shape conservation outcomes; and (iii) examining how fish assemblages, habitats and fisheries change in response to range shifts of tropical species that move south with rising sea temperatures.

Keywords: coastal waters, estuary, fish, fisheries, habitats, marine reserves, reef, seascape ecology, seagrass

Introduction

Moreton Bay contains a diverse fish fauna that is of immense cultural, social and economic value to a broad range of people (1, 2). Historically, the region was an important fishing area for Indigenous Australians (3, 4); it now attracts large numbers of recreational anglers each year (5, 6) and supports significant commercial fisheries (7, 8) (Thurstan *et al.* 2019, this volume). Many fish species are prized by recreational anglers (9, 10) or are harvested in commercial fisheries (7, 11). The region also provides essential habitat for numerous fish species that are of international conservation significance (12–14).

Descriptive accounts of fish catches date back to the early 1900s (15), but research on the biology and ecology of fish in Moreton Bay did not commence until the 1970s (1). Early studies described patterns in fish abundance, size and diet, and discussed how assemblages vary among habitats or between different parts of the Bay (16, 17). The range of fish research in the Bay is now considerably broader and encompasses a large body of publications on habitat use, health, trophic ecology and population biology (1, 18). The fish assemblages of Moreton Bay are diverse and of considerable value to the economy; but have also been heavily modified by the combined effects of water quality degradation, coastal urbanisation and fishing (2, 19, 20).

Synthesis of research on fish in Moreton Bay

To describe the thematic focus and distribution of research on fish in Moreton Bay, we reviewed published literature on fish in the region by searching the Elsevier Scopus and Thompson Reuters Web of Science databases using the keywords: 'Moreton Bay', 'fish', 'shark', 'ray', 'elasmobranch' and 'teleost'. This search yielded 166 studies (Table 1) with most focused on describing how fish use different ecosystems as habitat (n=69). A sizable proportion of research also addressed questions about fish health (n=58), trophic ecology (n=38) and population biology (n=25). Fewer studies have examined the impacts of human activities on fish populations (n=21), the benefits of conservation for fish (n=15) or the effects of fish on ecological functions (n=12). Therefore, examining the combined effects of human pressures on fish assemblages, identifying the ecological features of seascapes that affect conservation performance, and testing whether, and how, fish modify ecosystem functioning will be promising avenues for future research.

Research on how fish use habitats in Moreton Bay is dominated by studies in seagrass meadows (n=20), coral and rocky reefs (n=19), and sand/mud flats (n=17) (Table 1). Less research has been done on fish in mangrove forests (n=11), estuaries (n=10), urban waterways (i.e. canals, artificial lakes, modified estuaries) (n=7), saltmarshes (n=5) and the surf zones of ocean beaches (n=2). The body of research on fish health primarily comprises descriptive studies of fish parasites (n=55) and the accumulation of toxins in fish tissues (n=3). Research on fish trophic ecology encompasses studies of fish diets (n=29) and food webs (n=9). Studies of fish population biology include research on reproduction (n=12), movement (n=7), growth (n=7), morphology (n=3) and behaviour (n=3). Research on human impacts has examined the ecological effects of heavy fishing pressure (n=8), urbanisation (n=8) and water quality degradation (n=5) on fish populations. Conservation research has focused on the effectiveness of marine reserves (n=12) for fish and the ecology of threatened fish species (n=4). Functional ecology research has examined the role of fish in performing herbivory (n=8), predation (n=3) and scavenging (n=2).

Table 1: Summary of research on fish in Moreton Bay illustrating focal research themes, and the number of studies and citations for each topic (n=166).

Research themes	Studies	References
Habitat	**69**	
Seagrass	20	(10, 13, 21-38)
Reef	19	(19, 20, 39-55)
Sand/mud flat	17	(11, 17, 21-23, 26, 29, 38, 56-65)
Mangroves	11	(21, 22, 25, 29, 37, 41-43, 65-68)
Estuaries	10	(11, 21, 22, 29, 62, 63, 69-72)
Urban shores	7	(63, 71-75)
Saltmarsh	5	(76-80)
Surf zones	2	(9, 81)
Health	**58**	
Parasites	55	(82-136)
Toxins	3	(137-139)
Trophic ecology	**38**	
Diet	29	(21, 23, 30, 32-34, 38, 45, 46, 49, 52, 63, 64, 66, 70, 75, 76, 79, 80, 140-
Food webs	9	(40, 41, 59, 69, 71, 72, 150-152)
Population biology	**25**	
Reproduction	12	(3, 14, 140, 153-161)
Movement	7	(13, 14, 16, 162-165)
Growth	7	(38, 140, 156, 159, 160, 166, 167)
Morphology	3	(168, 169)
Behaviour	3	(35, 170)
Human impacts	**21**	
Fishing	8	(36, 52, 143, 171-175)
Urbanisation	8	(9, 63, 71-74, 176, 177)
Water quality	5	(10, 20, 45, 47, 62)
Conservation	**15**	
Marine reserves	12	(10, 11, 13, 19, 20, 31, 42, 43, 45, 47-49, 54)
Threatened species	4	(13, 14, 62, 167)
Functional ecology	**12**	
Herbivory	8	(20, 32, 33, 45, 46, 49, 141, 145)
Predation	3	(64, 66, 145)
Scavenging	2	(63, 70)

Fish diversity in Moreton Bay

The fish assemblages of Moreton Bay are diverse and comprise at least 1,190 species (12, 17). This diversity reflects the subtropical location of the Bay and the range of tropical and subtropical taxa it supports; one-third of all fish species in the region are at the latitudinal limit of their known distribution (1, 12). More tropical species are expected to arrive as sea temperatures rise (20, 49). The high diversity also indicates that Moreton Bay is a heterogeneous seascape that contains a rich mosaic of fish habitats (18, 44, 179).

Recent studies have sampled fish from surf zones (9), estuaries (11), soft Bay sediments (65), mangroves (65), seagrass meadows (10), inshore reefs (19) and offshore reefs (53) with baited remote underwater video stations (BRUVS). Fish species richness was greatest on offshore reefs, followed by structurally complex habitats within Moreton Bay, including reefs and seagrasses (Fig. 1). By contrast, few species appear to inhabit the shallow waters of mangroves, the soft sediments of estuaries, the central Bay or adjacent surf zones. These differences in fish species richness may result from variation in structural complexity, habitat heterogeneity and water depth across ecosystems (28, 42, 47, 53). This hypothesis has not been tested using empirical data. Survey effort has, however, been concentrated in estuaries, seagrasses and inshore reefs (Fig. 1), and we suggest that there might be numerous species that are yet to be recorded from mangroves, surf zones and offshore reefs (9, 53).

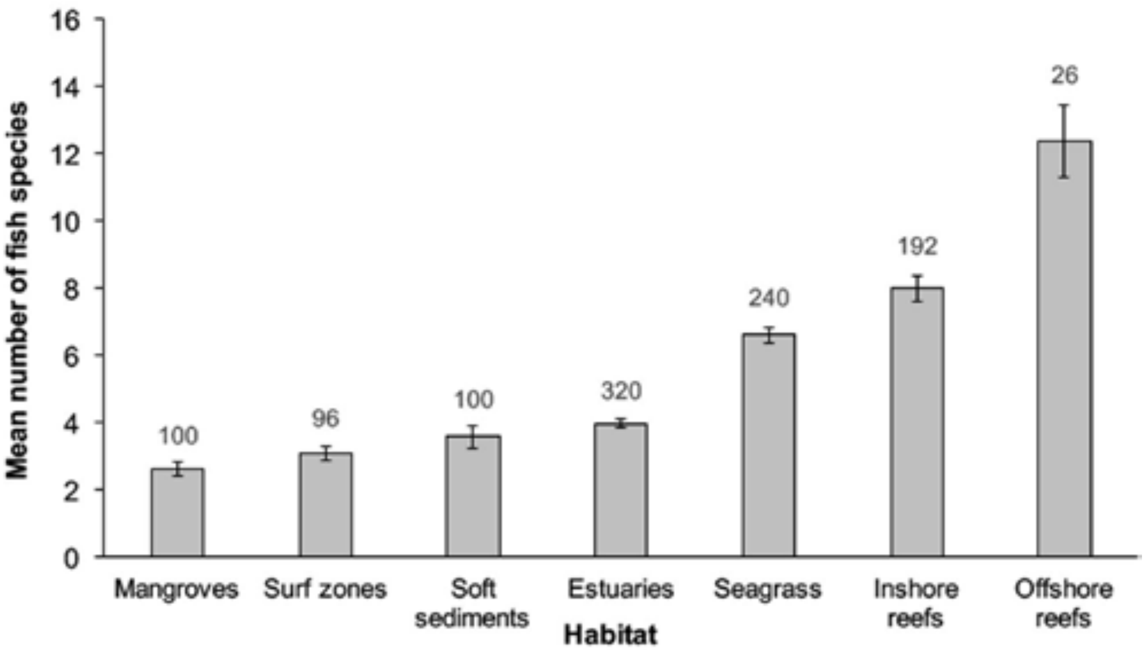

Figure 1. Mean number of fish species observed (± SE) in one hour from baited remote underwater video stations (BRUVS) deployed in seven habitats in Moreton Bay. Survey effort (i.e. total one-hour BRUVS deployments) is displayed for each habitat type above bars. Data based on surveys in mangroves, surf zones, soft Bay sediments, estuaries, seagrass meadows, inshore reefs and offshore reefs (9, 10, 19, 63, 65).

Ecological roles of fish habitats

Fish use different habitats as feeding areas, refuges from predation, spawning sites and juvenile nurseries, and as stepping stones during migrations from inshore to offshore waters (1, 18). Whilst these purported habitat functions are frequently cited as important factors thought to structure the spatial distribution of fishes, they are rarely explicitly tested (44).

There is clear empirical evidence that fish forage in the saltmarshes (76), mangroves (66), intertidal flats (64), seagrasses (32), surf zones (9), coral reefs (46) and rocky reefs (53) of Moreton Bay. There is little data, however, to link primary production from these habitats to changes in fish nutrition and growth. The strongest trophic links are for seagrasses and mangroves, which support fish nutrition both within these habitats and across adjacent seascapes (41, 59, 150). The role of habitats in providing a refuge from predators has been tested in predation experiments (using tethered whiting, *Sillago* spp.) in mangrove forests, intertidal mudflats and seagrass meadows, and is supported for both mangroves and seagrasses (66).

The location of spawning sites has not been formally reported for most fish species. Data on spawning and breeding aggregations are available for: trumpeter whiting (*Sillago maculata*) (159) and double-ended pipefish (*Syngnathoides biaculeatus*) (160) from seagrass meadows; sea mullet (*Mugil cephalus*) (16) and tailor (*Pomatomus saltatrix*) (180) from coastal-shelf waters; pink snapper (*Chrysophrys auratus*) (54) and grey nurse sharks (*Carcharias taurus*) (14) from offshore reefs; and yellowfin bream (*Acanthopagrus australis*) (165) and sand whiting (*Sillago ciliata*) (154) from surf bars where Moreton Bay joins the open sea.

Saltmarshes, mangroves and seagrasses in Moreton Bay are widely reported to provide nursery habitats for many fish because they support abundant juveniles (21, 67, 79). To function as an effective nursery for juvenile fish, habitats must also promote fish growth and survival, and allow individuals to migrate to adult habitats and reproduce (181). These criteria are, however, difficult to test and have not been sufficiently examined for most habitats in Moreton Bay (1, 18). Seagrasses provide the best evidence for the nursery function as they can be hotspots for larval recruitment and support abundant juveniles that grow rapidly in the seagrass meadows before migrating to other habitats as adults (29, 182, 183).

Many fish species migrate from habitats within Moreton Bay to spawn over surf bars (165) or move from shallow juvenile habitats to deeper adult habitats in offshore waters (40). Others move into Moreton Bay from offshore habitats to feed, or spawn, in estuarine habitats (54). On these inshore-to-offshore migrations, the shallow reefs of central Moreton Bay play an important role as stepping stones for some species, including sea bream (Sparidae), tropical snapper (Lutjanidae) and grouper (Serranidae) (44, 50).

Fish modify ecosystem functioning

Fish perform many significant ecological functions in ecosystems (e.g. herbivory, predation, scavenging) that help to sustain biodiversity, maintain the structure of food webs and modify the composition of benthic communities, including coral reefs, seagrass meadows and kelp forests (184–186). In Moreton Bay, fish are functionally important herbivores and predators that modify food webs in mangrove forests (41, 66), seagrass meadows (32, 145) and coral reefs (19, 46). Furthermore, herbivorous fish consume algae that might otherwise overgrow seagrass and corals in Moreton Bay (45, 187); a function that improved the capacity of both ecosystems to recover from flood impacts in 2011 (20, 188).

Fish are also prominent scavengers that consume animal carcasses and recycle nutrients in coastal food webs (189). In Moreton Bay, the consumption of carrion by estuarine fish is sensitive to changes in water quality, fishing pressure and urbanisation, and might prove useful as an indicator of ecosystem health (63, 70).

Connectivity shapes fish assemblages and food webs

Fish move among habitats in coastal waters to feed, spawn and disperse, and this functionally links populations, food webs and habitats across seascapes (183, 190, 191). In Moreton Bay, seascape connectivity (i.e. spatial linkages among habitats) alters the composition of fish assemblages in mangrove forests (43), seagrass meadows (28), coral reefs (44) and surf zones (9). These effects of connectivity shape the spatial distributions of many fish populations (10, 42), alter food-web structure (41, 150), modify ecological functions (45, 145), and can change the composition of benthic communities (20, 46). For example, herbivorous dusky rabbitfish (*Siganus fuscescens*) are most abundant on coral reefs near mangroves (43) (Fig. 2a). They migrate on the rising tide into mangroves to feed, and the contribution of mangrove carbon to their diet decreases with reef isolation (41) (Fig. 2b). Dusky rabbitfish also consume algae on coral reefs, and their feeding activities help to both reduce the cover of turf algae and increase the number of coral recruits on reefs near mangroves (45) (Fig. 2c).

Human pressure on fish assemblages

The fish assemblages and fish habitats of Moreton Bay have been substantially altered by human actions, including eutrophication (20, 47), sedimentation (10, 188), urbanisation (9, 74) and fishing (10, 55). Changes in water quality have detrimentally impacted the condition of numerous fish habitats (20, 188), altering the composition and abundance of fish assemblages in estuaries (62), seagrass meadows (10) and coral reefs (19). Fish diversity in mangroves, seagrasses and over coral reefs is also strongly correlated with water quality and declines from east to west across Moreton Bay with increasing distance from the open ocean (Udy *et al.* 2018, this volume) (Fig. 3a).

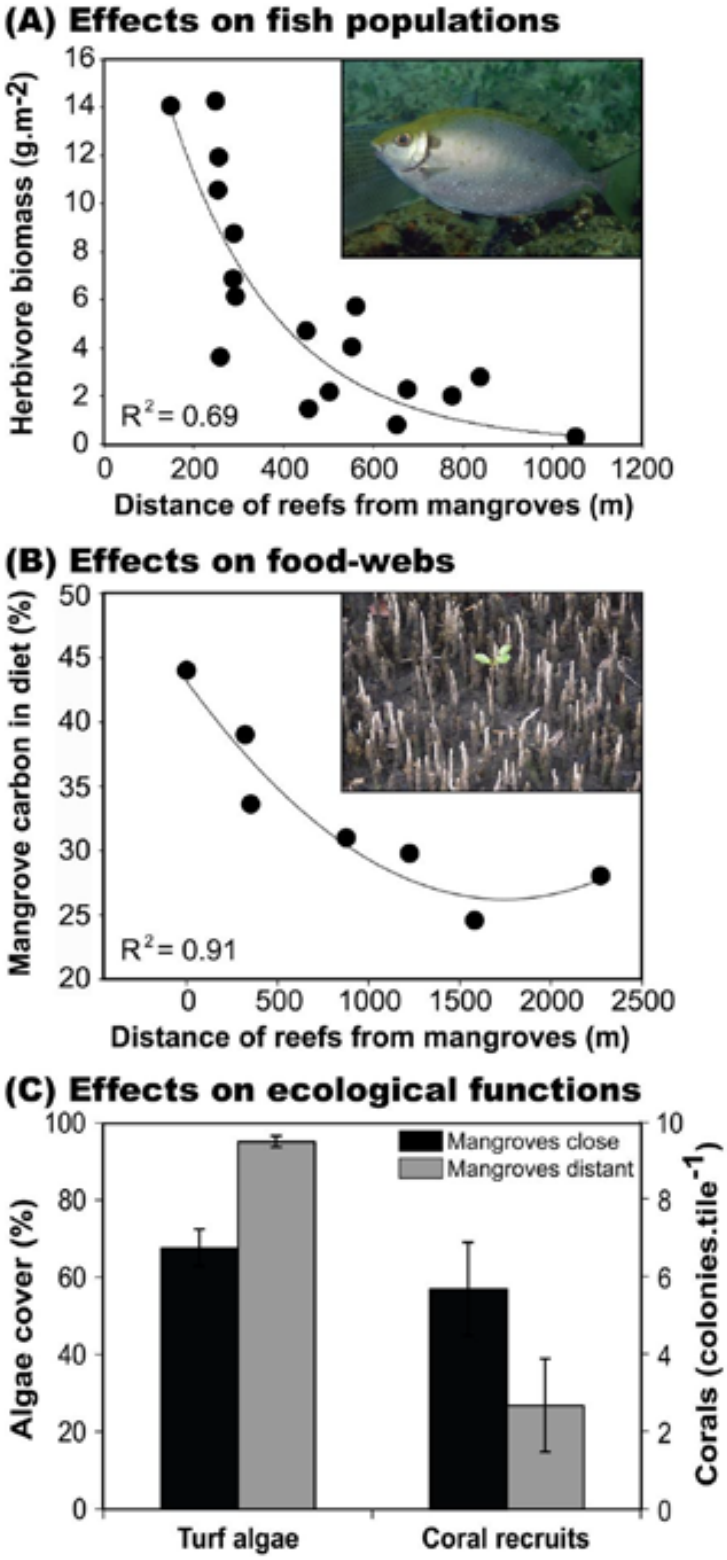

Figure 2. Seascape connectivity shapes fish assemblages, food webs and ecological functions in Moreton Bay: (a) herbivorous rabbitfish (*Siganus fuscescens*) are most abundant on coral reefs near mangroves (34); (b) they migrate tidally into mangroves to feed and the contribution of mangrove carbon to their diet decreases with reef isolation (28); and (c) they consume algae on coral reefs and this reduces the cover of turf algae and increases the number of coral recruits on reefs near mangroves (67).

Coastal cities abut many ocean beaches in the region, and extensive networks of canals and artificial lakes have been constructed in the estuaries of Moreton Bay (18). These urban shorelines provide habitat for fish, but typically support different fish assemblages than natural habitats (9, 74). In estuaries, fish diversity is negatively correlated with the cover of urban land in adjoining catchments, whereas in the surf zones of ocean beaches fish diversity is greatest adjacent to beaches that have been moderately urbanised (Fig. 3b). Furthermore, some fish species (e.g. yellowfin bream; snub-nosed garfish, *Arrhamphus sclerolepis*) have capitalised on the regular supply of food and abundance of shelter in urban estuaries. Yellowfin bream are important scavengers that aggregate under artificial structures where they consume carrion and recycle nutrients (63). Snub-nosed garfish are also common in artificial waterways and have adjusted their diet in response to urbanisation; they consume seagrass and crustaceans in natural estuaries, but feed on algae and insects in canals (72).

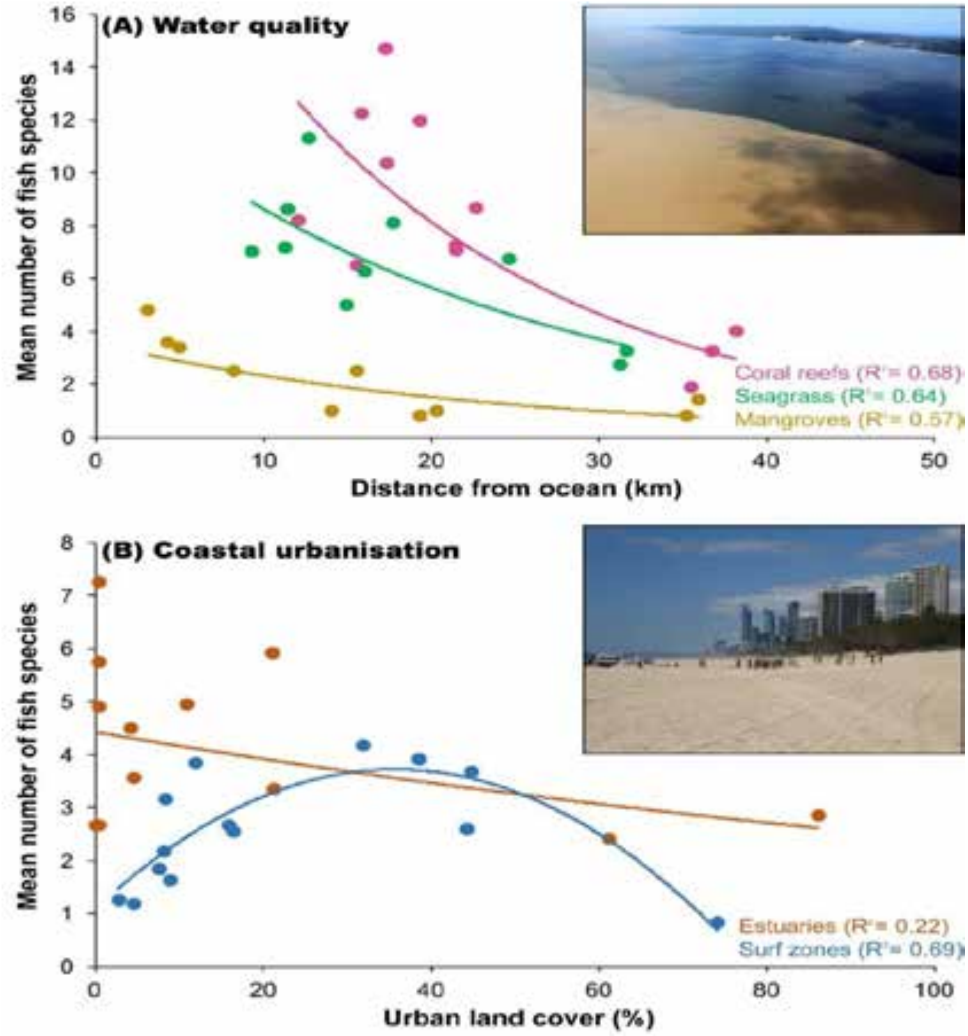

Figure 3. Effects of water quality (a) and coastal urbanisation (b) on the mean number of fish species observed on BRUVS deployments in coral reef, seagrass, mangroves, estuaries and surf-zone habitats in Moreton Bay (9, 10, 19, 63, 65). Water quality effects were indexed as the position of sites along Moreton Bay's strong west-east gradient in physico-chemical water quality (18, 19). Coastal urbanisation was measured as the percentage cover of urban land bordering each study site (9, 11).

Moreton Bay supports both recreational and commercial fisheries that extract sizeable numbers of fish each year from the Bay, ocean beaches of barrier islands, and offshore reefs (5–7). These fisheries are tightly managed to ensure the sustainability of individual fish stocks (Thurstan *et al*. 2018, this volume). However, the impacts of fishing and other anthropogenic activities, including pollution and degradation of water quality, have contributed to changes in the composition of fish assemblages and declines in the ecological condition of some seagrass meadows (10, 192), coral reefs (45, 55) and soft-sediment epibenthic communities (193). Well-designed and managed marine reserves can be effective at promoting the abundance of harvested fish and reversing the impacts of fisheries on fish habitats (190, 194). In Moreton Bay, fish assemblages differ between reserves and fished locations in estuaries (11), seagrass meadows (10) and coral reefs (43) (Fig. 4), but not in the surf zones of ocean beaches (195, 196). Existing reserves that conserve seagrass and reefs in the Bay support greater numbers of numerous harvested species, whereas reserves in estuaries support fewer harvested fish (Gilby et al 2018, this volume). These differences in the effectiveness of reserves among habitats are not linked to variation in reserve size, but might reflect differences in the ecological value of the seascapes that are targeted for conservation (10, 11, 43). Furthermore, reserves work better for many reef fish when they conserve reefs and mangroves that are close together (42).

Many tropical fish species are moving towards the poles with rising sea temperatures, and their arrival in higher latitudes is altering the composition of fish assemblages and the structure of subtropical and temperate fish habitats (197–199). The coastal waters of Moreton Bay are experiencing species range shifts and are recognised as a potential refuge for tropical species that are migrating south with climate change (200, 201). Consequently, we require empirical data to test how the fish assemblages, habitats, and fisheries of Moreton Bay are changing in response to the arrival of tropical species (49).

Conclusions

Moreton Bay supports a high abundance and diversity of fish, many of which are caught by recreational anglers and commercial fishers (1, 2). Most research on the fish of Moreton Bay has focused on describing how fish use different ecosystems as habitat (24, 67, 79), or addressed topics relating to fish health (101, 128, 137), trophic ecology (41, 142, 150) or population biology (13, 38, 157). Fish assemblages have been sampled with reasonable intensity in mangroves (43), seagrass beds (27) and inshore reefs (19), but few published data exist for subtidal sediments (23), surf zones (9) and offshore reefs (53). Whilst some functions of fish habitats are widely cited or posited, few studies have explicitly tested either the ecological roles of fish habitats (67, 76, 165), or the ecological functions fish perform in different habitats (46, 63, 66) in Moreton Bay. Fish diversity is typically high over coral reefs and seagrass meadows, and comparatively low in shallow mangroves and over unconsolidated soft sediments (e.g. sandy and muddy substrates in estuaries, Bay waters and surf zones) (9, 10, 19). However, many species and individuals move among habitats, and this exchange of

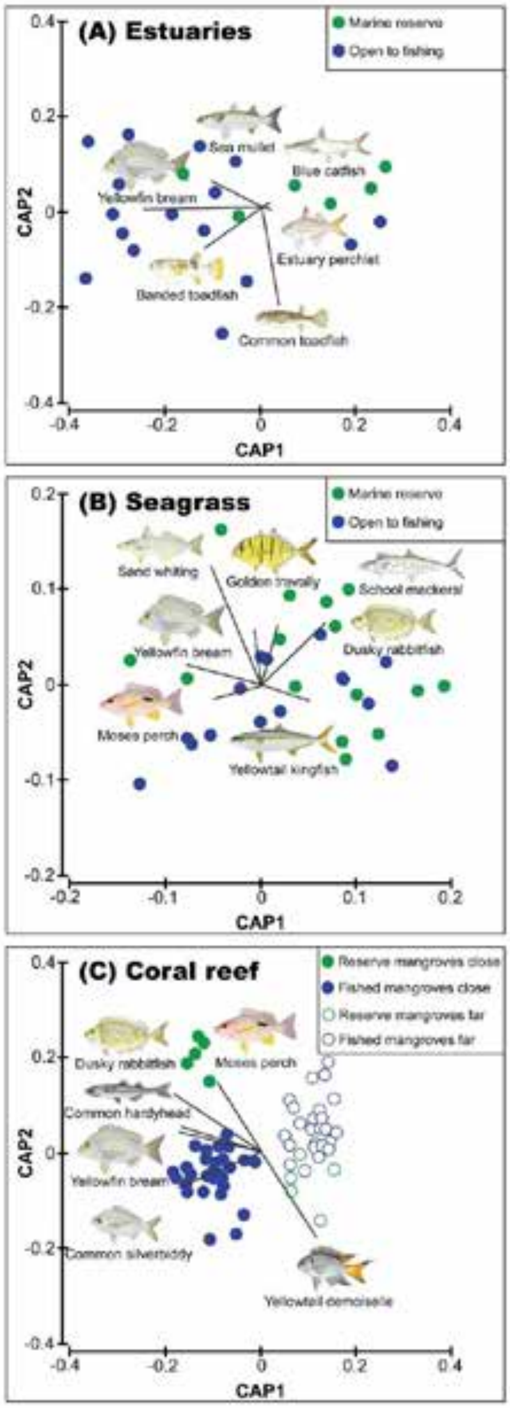

Figure 4. Canonical analysis of principal coordinates (CAP) ordinations illustrating differences in the composition of fish assemblages between marine reserves and fished locations. Individual dots represent the fish assemblages at each site surveyed. In estuaries (A), most species are more abundant in fished locations than in reserves (note the overlap of green and blue dots) (11). In seagrass meadows (B), several species are more abundant in reserves (note the separation of green and blue dots) (10). On coral reefs (C), most species were more abundant in reserves, but only when protected reefs were also close to adjacent mangroves (note the separation of solid green and blue dots, but not outlined dots) (43). Fish illustration and vectors display species correlations with canonical axes. For example, yellowfin bream were most abundant in: (A) estuaries that were open to fishing; (B) seagrass meadows that were protected in reserves; and (C) reefs that were both protected in reserves and close to mangroves. Fish illustrations sourced from www.efishalbum.com.

individuals functionally links assemblages, food webs and ecosystems across the seascape of Moreton Bay (41, 50, 191).

The fish assemblages of Moreton Bay have been altered by the effects of water quality degradation, coastal urbanisation and fishing, which have combined to reduce fish abundance and diversity in estuaries (63), seagrass meadows (27), coral reefs (19) and the surf zones of ocean beaches (9). Marine reserves that prohibit fishing are effective at promoting the abundance of harvested fish over seagrass meadows (10) and coral reefs (43) in Moreton Bay, and have also improved the capacity of these ecosystems to withstand disturbance (e.g. the recovery of coral reefs from flood impacts in 2011 (20)). We propose three broad and interconnected research fields that are likely to improve fish conservation and fisheries management in Moreton Bay in the coming decades: (i) evaluate effects of multiple human pressures on fish assemblages and fish habitats (e.g. 48, 63); (ii) identify the ecological features of habitats and seascapes that promote marine reserve performance (e.g. 11, 190); and (iii) determine how the arrival of tropical species that move south with rising sea temperatures will functionally change fish assemblages, habitats and fisheries in Moreton Bay (e.g. 46, 49).

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