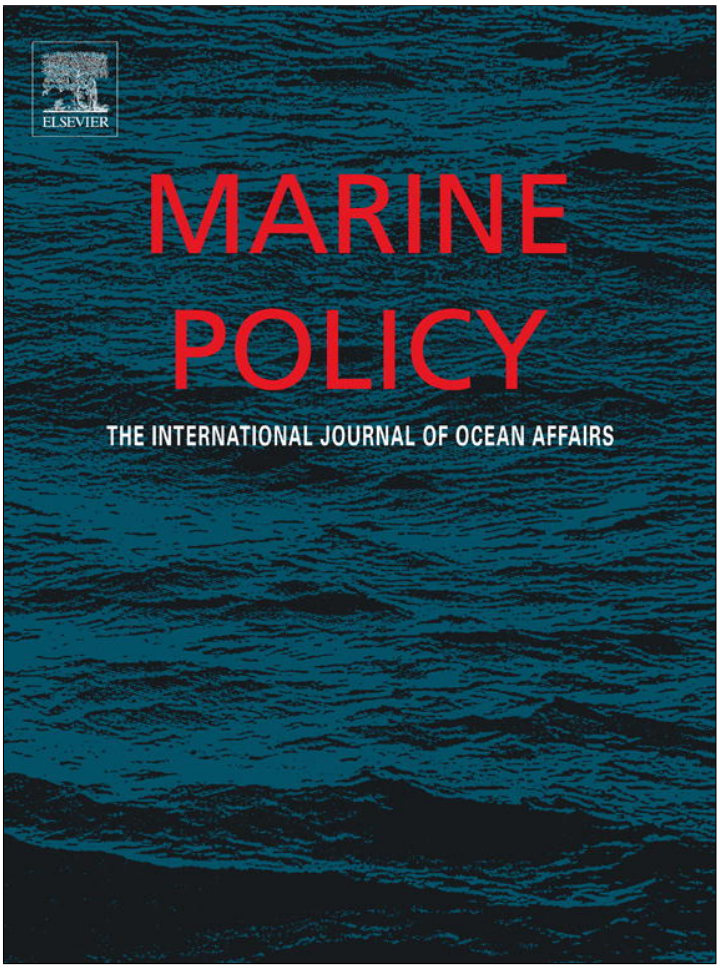

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Impacts of the Moreton Bay Marine Park rezoning on commercial fishermen

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ABSTRACT

The design of marine protected areas now typically incorporates socioeconomic data to minimize potential negative impacts on stakeholders. However, these data have limitations that are not well understood. Furthermore, whether the application of socioeconomic data in planning actually reduces avoidable negative impacts on stakeholders is rarely evaluated. This study assessed impacts on commercial fishermen of the rezoning of the Moreton Bay Marine Park, in south eastern Queensland. Specifically, this study (1) compared estimates of opportunity costs of new no-take zones from before and after the rezoning was implemented, and (2) identified impacts of the new zoning scheme on fishing businesses and changes to working environment. Although estimates of aggregated opportunity costs before implementation matched those reported afterwards, these costs varied strongly between types of fisheries and individual fishing businesses. A large proportion of fishermen reported loss of fishing grounds. Some have found new grounds but reported that their travel times have increased and that the remaining open grounds are overcrowded. Fishermen have attempted to adapt to this new situation by changing the time spent fishing or diversifying into other fisheries, which required investing in new gear. The effectiveness of a structural adjustment package to compensate fishermen and minimize displacement of effort was limited by poor information on the number and use of commercial fishing licences and little understanding of the dependence of individual fishing businesses on particular fishing grounds. Ways of improving fisheries data for conservation planning and designing adjustment packages to more effectively mitigate impacts of MPAs on commercial fishermen are suggested.

Introduction

Globally, a growing population has resulted in increased pressure on marine resources [1]. In turn, this has increased the need for conservation efforts and resource management in the marine environment [2,3]. Marine protected areas (MPAs) [4], multiple-use areas in which extractive use is regulated, can be designed to achieve objectives for both conservation and resource use, and are therefore considered instrumental in mitigating the decline of marine resources [5]. Systematic conservation planning, a framework used to design protected areas to meet explicit conservation goals [6], is considered best practice for MPA design and has been used across the globe (e.g., Australia, the United States, South Africa [7–9]).

The inclusion of socioeconomic data in MPA design allows planners to select areas that meet objectives for biological conservation, whilst minimizing impacts on stakeholders [10–12]. Minimizing the impacts on stakeholders reduces conflict between resource users and the agency undertaking planning and ensures the MPA design is cost-efficient [10]. The most common socioeconomic consideration in marine protected area design is opportunity cost to fishers, typically captured with data on catch per unit effort (CPUE) [10]; however, there are well documented limitations of data on CPUE. Annual CPUE data, as used in conservation planning to date, produce a snapshot of current fishing effort that does not account for inherent temporal variability in fisheries or potential adjustments in fishing behaviour. Adjustments in behaviour of fishers are based on their synthesis of large amounts of information to inform decisions about when, where, and how to fish, considering variables such as price, weather, and management regulation [13]. In addition, CPUE data are often recorded at coarse resolution so the profitability of small fishing grounds can be missed or underestimated, leading to their

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inclusion in proposed marine reserves and increasing conflict with fishermen [11]. Further, CPUE data capture only current effort which might not reflect future effort, particularly if the mobility of the fishing fleet changes through time or if currently fished areas become unavailable through the establishment of MPAs [14].

In addition to the limitations presented by data on CPUE, there are two notable limitations of methods to include opportunity costs in decision support tools for MPA design: 1. data are typically aggregated across different types of fisheries; and 2. data are aggregated across individual businesses. Aggregation simplifies data for use in conservation planning software such as Marxan, but fails to capture the variable impacts on different user groups. Aggregation can result in inequitable distributions of costs across groups, undermining the long-term success of conservation efforts [15]. The recently released Marxan with Zones allows for costs to be assigned to separate fishing groups [16]. However, even this capability is likely to obscure the variable impacts of marine reserves on individual fishing businesses. Understanding variable impacts across businesses is important if structural adjustment packages, aimed at reducing displaced fishing effort from MPAs, are to be well aligned with the MPA design and effective in achieving equitable outcomes for stakeholders.

Apart from opportunity costs there are other costs of MPAs related to adaptation of businesses and changed working environments [17,18]. Examples of costs currently not captured in marine planning processes include closing off traditional fishing grounds, displaced fishing effort, forced gear diversification, increased travelling and fishing times, and overcrowding [18–20]. Commercial fishers can have a very strong "sense of place" or connection with specific locations having characteristics that make them special or unique and foster authentic human attachment and belonging [21,22]. In some areas, informal tenure agreements exist that can be disrupted by MPAs, leading to disputes over the remaining fishing grounds [23].

To be successful, MPAs require community support. Integral to gaining the support of communities is understanding and quantifying the impacts of MPAs on fishing activities and fishing businesses [24,25]. The 2009 rezoning of the Moreton Bay Marine Park is used as a case study to examine its perceived impacts, including non-financial costs, on commercial fishermen. Specifically this paper has two objectives. The first is to compare government predictions of opportunity costs of rezoning to the pre-rezoning and post-rezoning opportunity costs estimated and reported, respectively, by the fishermen. This comparison provides insights into the effects of the rezoning on total fisheries income, on income by fishery type and, importantly, on the variability of impacts across individual fishing businesses. The second objective is to identify the impacts of rezoning on operation of fishing businesses and the working environment of fishermen. Areas of future research are suggested to improve marine protected area design by better accounting for impacts on fishermen and consequently increasing the social acceptability of and support for MPAs.

Materials and methods

Study area

Moreton Bay Marine Park is located in south-east Queensland, Australia (Fig. 1). Moreton Bay Marine Park is characterised by highly productive and diverse marine ecosystems [26,27]. The area around Moreton Bay is home to nearly three million people, many of whom utilize the marine park for a variety of activities including recreational and commercial fisheries [26,28]. Moreton Bay Marine Park encompasses 3400 square kilometres and was

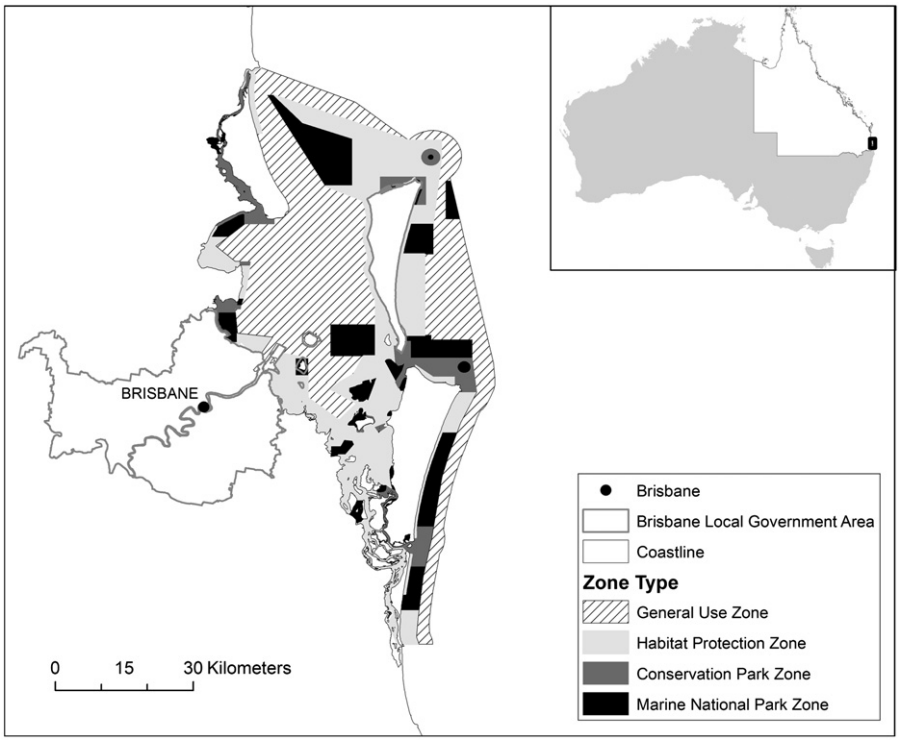

Fig. 1. Location, boundaries and geographical setting of Moreton Bay Marine Park. The centre of Brisbane and the boundaries of the Brisbane local government area indicate the extent of the city and its proximity to the Bay. The Moreton Bay Marine Park boundaries and zones are shown (permitted activities in each zone are in Table 1). The inset shows the state of Queensland with the location of Moreton Bay Marine Park in black.

originally zoned in 1993 with 0.5% designated as no-take zones [29]. In 2007, a review of the zoning plan was required by legislation. The review resulted in a new zoning plan that increased the level of no-take zones to 16% of the marine park area, although the boundaries of the marine park remained unchanged [29]. The rezoning followed a similar systematic planning process as that used for the Great Barrier Reef Marine Park [30]. Extensive biophysical and socioeconomic datasets were used to select zones with specific gear exclusions compatible with varying ecological goals [29]. The zoning plan includes four types of use zones, ranging from general use with few restrictions to no-take zones with extensive restrictions (Table 1). The new zoning plan was implemented on the 1st of March 2009.

There are five main commercial fisheries within the Moreton Bay Marine Park: otter trawl, net, crab, line, and beam trawl. However, there is considerable uncertainty about the total number of commercial fishermen who actually operate within Moreton Bay Marine Park. One reason is that fishing businesses can hold more than one licence. Another reason is that some fishermen have licences to fish in Moreton Bay Marine Park but, for various reasons (e.g., distance from home), choose not to fish there. For example, between 2003 and 2006 there were, on average, 418 licences that permitted fishing within Moreton Bay Marine Park [29]. However, logbook data from the Department of Primary Industries and Fisheries (DPIF) showed that, in 2006, only 203 licences drew 80% or more of their revenue from inside Moreton Bay Marine Park [31]. Furthermore, commercial fisheries associations estimated that, in 2006, there were only 120 commercial fishermen active within Moreton Bay Marine Park [31]. Differences between the total number of licences and reported active fishermen also result from fishermen defining "active" in different ways, different definitions amongst fishermen of the Moreton Bay area, and limited communication between fishermen operating in different fisheries. The uncertainty related to the number of active fishermen within Moreton Bay has implications for fisheries management generally and, specifically, the government's ability to properly manage structural adjustment packages associated with the rezoning.

Methods for surveying fishermen

To investigate the impacts of the rezoning as well as how fishermen have adapted, data was collected pre and post 2009 rezoning of Moreton Bay Marine Park. The pre-rezoning data were collected in 2007. They included surveys of fishermen undertaken by the Moreton Bay Access Alliance (MBAA) before the new zones were known [31] and, after the extent and location of the new zones were decided, estimates by the state government of the impacts of rezoning per fishery (in gross value production) [29]. To collect post-rezoning data, a survey similar to that used by the Moreton Bay Access Alliance in 2007 was developed to ensure consistency between the two datasets (see appendix for survey). Survey questions focused on financial impacts, adaptation strategies to the new zones, and open-ended questions about other related impacts. The post-rezoning data were collected between May and August 2010.

The 2010 survey was sent by mail to the same fishermen who took part in the Moreton Bay Access Alliance's survey in 2007. In 2007, Moreton Bay Access Alliance received responses from 80 of the 120 fishermen estimated to be active within the Moreton Bay Marine Park [31]. The 2010 survey was sent to 65 of those 80 fishermen (all fishermen with available addresses). Six declined to participate and 12 surveys were returned completed. There was considerable disquiet among fisherman about the rezoning and the value of participating in the surveys. Due to the low response rate of the mail survey, data was supplemented with a semi-structured phone survey (see appendix for description of data collected from each survey). Among the remaining 47 fishermen who had declined to participate or not responded, 16 agreed to semi-structured phone interviews. This resulted in a total of 28 responses (43% survey response rate, 23% of estimated active fishermen). Three of the surveyed fishermen were no longer active in the industry, giving a sample size for quantitative analysis of 25. Typically the fishermen of Moreton Bay are active in, or at least licenced for, multiple fisheries [29]. Of the 25 respondents, 14 (56%) were licenced to work in the crab fishery, 19 (76%) in the net fishery, and 7 (28%) in the trawl fishery.

Comparison of estimates of opportunity costs

Three sets of data on estimated and reported opportunity costs to commercial fishermen of the rezoning were used to estimate the likely average impacts on income as well as the variation in financial impacts between fishermen. The three data sets used were: (1) government estimated impact on gross value product by fishery; (2) estimated impact on total income by fishery based on 2007 survey data collected from commercial fishermen in Moreton Bay Marine Park (intersected with new zones in this paper with the method described below); and (3) reported impacts on income based on 2010 survey data collected from commercial fishermen in Moreton Bay Marine Park.

To compare the opportunity costs of the 2009 rezoning estimated by government with those reported by the fishermen, the line and beam trawl fisheries were excluded due to insufficient data. The data on financial impacts from the 2007 survey of fishermen by the Moreton Bay Access Alliance were transformed to make them comparable to the government's estimates and 2010 data collected for this paper.

In the 2007 survey of fishermen by the Moreton Bay Access Alliance, effort for the crab, net, and trawl (beam and otter) commercial fisheries was categorised as having low, medium, high, and very high value, based on the relative proportion of income derived from each fishing ground for each fishery [31]. Fishermen had provided their gross income and were asked to delineate their fishing grounds and attribute percentages of their incomes to each fishing ground for each fishery (if they

Table 1
The four types of zones in Moreton Bay Marine Park, the main uses permitted in each, and the extent of each zone type in the 2009 zoning plan.

Zone type	Permitted uses	Area (km^2)	% of park
General use zone	Boating, line fishing, crabbing, trolling, bait gathering, bait netting, netting (other than bait netting), limited spearfishing, limited collecting, trawling	1581	46
Habitat protection zone	Boating, line fishing, crabbing, trolling, bait gathering, bait netting, netting (other than bait netting), limited spearfishing, limited collecting	1040	30
Conservation park zone	Boating, line fishing[a], crabbing[a], trolling, bait gathering, bait netting, netting (other than bait netting), limited spearfishing, limited collecting	260	8
Marine national park (no-take) zone	Boating	543	16

[a] With quotas on the number of hooks per angler and the number of crab pots per person.

participated in multiple fisheries). For each fishery, fishing grounds were then aggregated across fishermen and assigned a category (low, medium, high, and very high) based on the relative proportions of total income that the area represented. The proportion of income attributed to each category differed by fishery.

To calculate the loss of income by fishery due to the zoning from the 2007 survey data, the weighted mean loss in income was calculated to reflect the uneven contributions of fishing grounds to total income (e.g., fishing grounds categorized as very high value might be 10 times more important than fishing grounds in the low category). To calculate the weighted average loss of income by fishery, the relative proportion of income associated with each category by fishery was translated into a weighting of 1–10. For example, if a low-value area represented 10% or less of total income it was assigned a weighting of 1. Weightings are not disclosed in this article because they can be converted back to aggregate and personal income data which would breach confidentiality agreements.

The zoning plan was then intersected with the fishing grounds to identify areas where each fishery had been precluded to determine the area of fishing grounds lost by income category. The weighted average loss of income was calculated for each of the three fisheries, i, using the derived weighted values for fishery i in each of the four income categories j, $w_{ij,}$ the total original fishing ground for fishery i in category j, a_{ij}, and the total lost fishing ground for fishery i in category j, l_{ij}:

$$\text{Weighted average loss of income} = \frac{\sum_{J=1}^{4} w_{ij} l_{ij}}{\sum_{J=1}^{4} w_{ij} a_{ij}}.$$

The weighted average loss of income calculated from the 2007 income data was then compared with the percentage of gross value product lost per fishery, as predicted by the Queensland Department of Environment and Resource Management (DERM) in its Regulatory Impact Statement and estimated from the 2010 surveys.

Adaptation of fishing businesses and changes to working environment

In the 2010 survey, the fishermen were asked open-ended questions to explore the impacts of the new Moreton Bay Marine Park zoning plan in relation to loss of fishing grounds, need to explore new grounds, change of fishing methods, and diversification into new fishing sectors. Any further comments about these topics were noted. Statistical analyses were not possible due to the small sample size ($n=25$), therefore only the percentage of fisherman reporting each type of change is presented.

Results

Comparison of estimates of opportunity costs

The three approaches to estimating impacts of the 2009 rezoning on income produced similar results when aggregated across fisheries (Table 2). The mean overall change in income reported in the 2010 surveys was −23.0%, compared to pre-implementation estimates of −20.5% (prediction by DERM, [29]) and −22.2% (weighted average loss of income derived from 2007 data from the Moreton Bay Access Alliance). There were, however, dissimilarities between estimates for individual fisheries. DERM's predicted impact on the net fishery was 11.2% higher than the estimate from weighted average loss. The impact on the trawl fishery as predicted by DERM was 16.6% lower than the estimate from weighted average loss.

Importantly, both the overall impacts on income and the impacts per fishery in Table 2 hide substantial variation in impacts on individual fishermen. The 2010 survey data indicated large variations in stated impacts, with individual reported changes ranging from negative to positive 100% (Fig. 2). Most fishermen reported losing between 26% and 50% of their income (mode −30%) after the new zoning plan, with important causes of reduced incomes being loss of fishing grounds and overcrowding in the remaining fishing grounds.

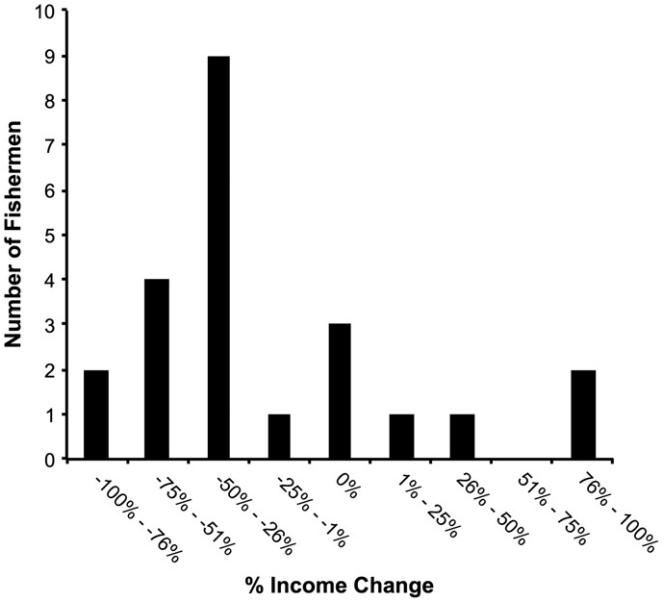

Fig. 2. Distribution of impacts on income due to the 2009 rezoning of Moreton Bay Marine Park, as stated by 25 fishermen in 2010. Mean change of income = −23%, mode = −30%.

Table 2
Impact of the 2009 rezoning of Moreton Bay Marine Park on income and fishing grounds. The estimate by the Queensland Department of Environment and Resource Management and the weighted average loss of income are based on data from 2007, before the new zoning plan was implemented. The stated impact on income is based on our survey from 2010, after the new zoning plan was implemented. The fishermen did not specify the impact on income per fishery, so only the total impact post-rezoning is known.

	Crab	Net	Trawl	Total
2007 estimated impact on income (%) (Department of Environment and Resource Management)	−17.6	−37.2	−6.7	−20.5
2007 estimated impact on income (%) (weighted average loss of income, derived from survey data compiled by the Moreton Bay Access Alliance)	−17.4	−26.0	−23.3	−22.2
2010 stated impact on income (%)				−23.0

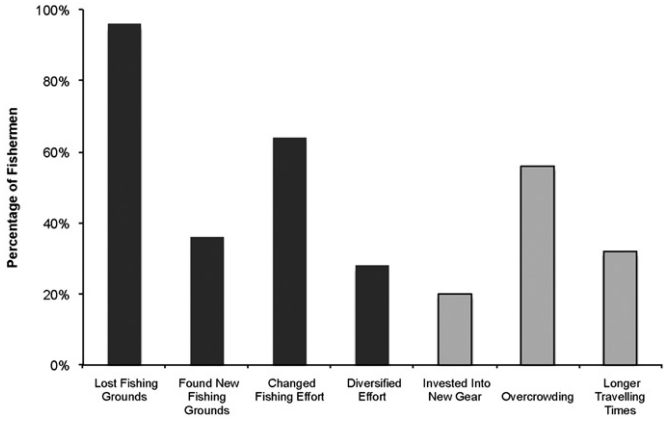

Fig. 3. Stated adaptations of fishing businesses and changes to working environment arising from the 2009 rezoning of the Moreton Bay Marine Park. The lighter bars indicate impacts that were mentioned without prompting in the surveys.

Adaptation of fishing businesses and changes to working environment

Seven types of adaptation of fishing businesses were reported to follow the rezoning (Fig. 3). The most commonly reported impact was loss of fishing ground (96%), while only 40% found new fishing grounds. Other impacts identified in open-ended questions were overcrowding on the fishing grounds, longer travel times associated with new fishing grounds (leading to increased fuel consumption and potentially lower net profit), and investments in new gear necessary to diversify into different fishing sectors.

In the open-ended questions, respondents stated that the rezoning led to a change in mentality whereby the fishermen in Moreton Bay became engaged in a race to fish [20]. As a result, fishermen reported that the remaining open areas were now being fished more intensively. Fishermen indicated that, before the 2009 rezoning, there had been a system of informal marine "tenure" within Moreton Bay Marine Park but this had been reduced since the rezoning because of the loss of fishing grounds. Fishermen who did not look for new fishing grounds after the rezoning claimed that they wished to respect the informal tenure system.

Fishermen also reported that the rezoning had reduced the practice of "farming" or fishing periodically and allowing fishing grounds to "rest" before fishing again. In the surveys, 56% (14/25) mentioned an increase in the number of fishermen in their areas to the extent that fishing grounds were overcrowded (Fig. 3), making it more difficult to fish effectively because fishing gear could not be deployed properly. For example, one respondent commented this way on overcrowding:

> There are more fishers in a smaller area. Before rezoning, areas could be "rested" for periods of time, now all areas are overfished. Catch rates have dropped.

Those fishermen who had found new fishing grounds stated an associated increase in their travelling times (Fig. 3), as put by one fisherman:

> My fishing time has increased mostly due to greater distances travelled to get past green zones.

Another reason was the need to search for fishing grounds, as put by another fisherman:

> I might spend a lot more time searching for fish or trying to hold shots since the rezoning because all the fishermen have moved into my traditional areas and vice-versa.

The increase in travelling time is a surrogate measure for increase in input costs such as time and fuel. Fishermen might adapt their fishing behaviour by staying out at sea for multiple nights instead of coming home every night, with potential effects on family life.

Those fishermen who reduced or maintained fishing effort stated that longer working hours were not feasible, either for personal reasons or due to constraints on the fishery, such as gear deployment being limited by tides, and legislative constraints (e.g., weekend closures). Increasing fishing time did not translate uniformly into increased income. Only 27% (3/11) of fishers who increased their effort also increased their incomes.

Another adaptation to the rezoning was entering a different fishery, thereby diversifying effort. In the survey, 28% (7/25) indicated that they diversified effort (Fig. 3), requiring investment in new gear and learning about new fishing grounds, as described by one respondent:

"Before closure, I primarily estuary netted. Most of those areas have become closed. In other areas it was hard to determine if they had been fished recently. It was also unknown territory. Therefore it was unknown where fish fed, held up, etc. In the areas I previously fished, I had approximately 100 years of knowledge that had been handed down through the generations of my family. Last year I had no choice but to invest significantly in a different fishery which I had not previously targeted as a primary source of income – sandcrabbing – this is also knowledge previously learnt but not previously utilised."

Discussion

The range of impacts of MPAs on fishers is poorly understood, and while the financial costs of MPAs to fishers have become increasingly incorporated into the design of MPAs [10], other impacts have rarely been quantified [but see 17,25,32,33].

The likely socioeconomic impacts of MPAs on stakeholders can be assessed both through the consideration of opportunity costs, to account for financial impacts, and further surveys and stakeholder consultations to refine financial data and identify other impacts. However, participatory practices in Australia have been limited, relying on mechanisms such as public meetings or leaflets [34,35]. A recent study found that fishers in the Great Barrier Reef Marine Park were generally unsupportive of the new zoning implemented in 2004, related to the perception that they had not been adequately engaged in the zoning process [18]. Post-implementation evaluation programs provide an important assessment of the actual socioeconomic impacts on commercial fishermen. However, retrospective evaluation programs are rarely implemented and the full effects on fishermen of MPAs often remain undocumented [but see 17,18,36,37], limiting the ability to predict them in subsequent rezoning exercises. This study examined the financial costs of the Moreton Bay Marine Park and identified related impacts on fishing businesses and working environments.

Comparison between the predicted opportunity costs of the rezoning and the opportunity costs reported by fishermen

The opportunity costs of the 2009 rezoning can be considered at three levels: (1) aggregated financial changes across fisheries; (2) financial changes in the crab, net and trawl fisheries separately; and (3) impacts on individual commercial fishermen. The

aggregated opportunity cost across fisheries, in terms of lost income stated by the fishermen, was relatively close to the figures predicted by state government and those derived from data collected by the Moreton Bay Access Alliance. Pre-rezoning estimates predicted very uneven effects on income between the individual fisheries and the two approaches to estimation diverged substantially for the net and trawl fisheries. The accuracy of these estimates could not be determined because, in the post-rezoning surveys, the fishermen were unwilling to specify how much they were earning from the different fishing sectors. At the level of individual fishing businesses, the opportunity costs of the rezoning varied greatly.

Notwithstanding estimates of impact by fishery, none of the data used in the rezoning recognized variable impacts on individual fishermen. This is not unexpected because opportunity costs are commonly aggregated across all fisheries for inclusion in decision support tools. Only recently have advances in tools such as Marxan with Zones allowed explicit consideration of costs to multiple stakeholder groups [38]. But even this new capability fails to address highly variable impacts on individuals. Aggregation of costs across (and even within) fisheries implies that selection of areas as marine reserves is intended to minimize the average cost across all fishers. However, the cost of any one fishing ground considered for protection will vary significantly between individuals because not all fishers depend equally on the same areas. This variability is highlighted in the survey results in which fishers noted the informal tenure system, indicating that any one fishing ground can represent a large portion of income for a few fishers but no income for many others. Similar outcomes have been described when total cost across stakeholders is considered in the planning process rather than disaggregating costs to stakeholder groups [15].

Three main improvements to data are needed to better account for opportunity costs to fishermen and to ensure that protected area designs are well aligned with programs, such as the Structural Adjustment Program implemented in Moreton Bay, intended to manage displaced fishing effort.

1. **Better accounting for the opportunity costs to individual fishermen.** Opportunity costs to fishers are often known at a coarse resolution through collection of CPUE data. These data can be refined through participatory processes such as the one undertaken by the Moreton Bay Access Alliance. The challenge is then for planners to assess the impacts of proposed MPA designs across individuals and gear types. Support for this type of analysis is being developed through extensions in decision support tools that provide more in-depth analyses of socio-economic impacts [39]. More sophisticated analyses across fisheries and individuals will help to ensure that displaced effort is managed more effectively. Specifically, these analyses should ensure that the individuals whose licences are bought are either inactive (latent licences) or incurring the largest financial impacts from the marine reserves.
2. **Understanding and mapping informal tenure systems.** If the informal tenure system said to be in place in Moreton Bay Marine Park had been mapped before the rezoning, the design of new zones could have either ensured more equitable impacts or identified fishermen who would be most adversely affected. There are precedents for this approach. For example, Weeks et al. [23] included local marine tenure boundaries explicitly in their planning process to stipulate a minimum area of fishing ground per community that remained open, thus ensuring equitable impacts of proposed MPAs.
3. **Understanding the temporal variability of fishing effort.** Many of the target species in Moreton Bay have strong seasonal variability of recruitment and abundance. These species include mud crabs [40], prawns [41] and net species such as bream [42]. Due to the seasonal nature of catches, some fishers diversify their fishing strategies across gear types and fishing areas to maintain catches during the year. Aggregating costs of marine reserves to fishers as annual values can therefore obscure the importance of fishing grounds for portions of years and fail to recognise that no-take zones in certain areas can render some businesses unviable. A recent study by Ban et al. [43] outlined the many unresolved research

Table 3
Potential costs of marine protected areas to fishermen, based on literature from around the world. Some impacts and adaptations to impacts interact with one another. Asterisks indicate negative impacts that, with effective engagement and management of MPA planning, can be reversed to become benefits. Ticks in the left column indicate impacts identified by the fishermen participating in this study.

Costs	Description	Identified in this study
Loss of fishing grounds	The disruption of formal and informal fishing tenure systems can interfere with informal marine resource governance systems and result in the loss of local knowledge [16,47,62]	✓
Overcrowding	Fishermen are forced to move away from areas where fishing is restricted, leading to increased density of fishermen in areas where fishing is allowed [16,18,47,49]	✓
Longer distances to fishing grounds and higher costs associated to new fishing grounds	New regulations can mean fishermen have to travel greater distances to alternative fishing grounds 46,47, requiring more fuel and other capital costs (e.g., equipment to locate fish) [20]	✓
Decrease in catch-per-unit effort (quality and quantity)/food security*	New fishing grounds, overcrowding, and lack of knowledge of new fishing grounds could reduce the quantity and quality of catch. If dependence on fish for food is high, reduced catches could result in changes to health of fishermen and their families [17]	
Loss of income*	Decrease in income could result from decrease in catch, decrease in the quality of the produce, or higher costs involved in fishing. These effects are likely to be result in diversification of livelihoods [17,49]	
Diversification of gear	Changes in rules governing resource use can lead to the need to invest in new gear and learn how to use it profitably [63]	✓
Conflict between fishers*	The movement of displaced fishermen other fishing grounds can lead to disputes, for example over allocations of catch or gear entanglements [20,49,52,64]	✓
Increase in safety risk	Fishermen might have to travel further to catch fish, increasing the likelihood of moving into less sheltered waters and encountering storms or other hazards [20,46,47]	
Loss of traditional fishing community*	Marginalised fishermen might be forced to leave the fishery because of higher costs or lack of fishing grounds [52]	
Disempowering of stakeholders*	New governance arrangements can revoke the existing governance ones and erode decision-making authority, shifting the balance of power between difference stakeholder groups [17,47,52]	
Impacts on cultural traditions or customary marine tenure*	Restrictions on fishing can change the traditional use of areas and undermine traditional governance systems [46]	

questions around using costs in conservation planning and emphasized the need to consider the dynamic nature of both the social and ecological aspects of marine ecosystems.

Fishermen's adaptations to the rezoning and changes to their work environment

Marine conservation plans should consider impacts on fishermen more comprehensively, given the potential of MPAs to (1) affect the well-being of fishers, especially those marginalised and most dependent on marine resources [17], and (2) compromise stakeholder support for establishing new MPAs. This study documented several impacts on fishermen's lifestyles and their ability to remain competitive. The kinds of impacts and adaptations by fishermen that were observed in Moreton Bay are common in other regions. Among those recorded elsewhere are loss of fishing grounds, overcrowding, higher costs, greater distances travelled to new fishing grounds, and the need for gear diversification (Table 3). The interviewees for this study attributed these impacts to both the rezoning and the design of the structural adjustment package that was intended to mitigate such impacts. The rezoning and subsequent movement of fishermen meant that the informal tenure system was disrupted. Some fishers with restricted fishing areas were not compensated and had to change fishing grounds and, in some cases, fishing gear.

Additional to the typical impacts of MPAs (Table 3), the interviewees identified a change in fishermen's attitudes, leading to more intensive practices and a "race to fish". This change can be explained by fishermen having limited ability to adapt to the new zoning. Marshall et al. [44] found fishers in northern Australia had high levels of attachment to fishing, with many unable to consider or ill prepared for other forms of employment. Fishers lacked the skills, attitudes, and opportunities to adapt to policy change [44]. Detailed understanding of the resilience of fishers to policy change [45], complex social structures [46], and territoriality [47] is likely to better mitigate negative social impacts of MPAs. Lessons from this study and others (Table 3) will hopefully inform future planning processes.

Similar to most studies investigating the socioeconomic impacts of MPAs, this study evaluated impacts only in the short term, but impacts are likely to change through time. For example, in New Zealand, perceived negative impacts decreased a few years after implementation of the Tonga Island Marine Reserve, likely due to the earlier assessment reflecting fishermen's more pessimistic expectations [48]. After two decades post implementation, the Okakari Point Marine Reserve in New Zealand had almost total support of local fishers [48]. Benefits associated with implementation of the reserve, such as increased catch, eventually outweighed costs but took many years to become obvious [20,49].

Ideally, MPA planning processes would accurately predict socioeconomic impacts in both short and long terms. However, the extent and spatial variability of impacts from MPAs can be predicted only with a very good understanding of the temporal and spatial drivers influencing fishing behaviour. Dalton [50] modelled the impact of reserves on fishermen's incomes, but had to assume fixed prices of goods and services and no depletion or degradation of resources. A model of changes in fisher distribution has also been attempted, but the dynamic nature and seasonality of the fishery was not incorporated [51]. The limitations of the present understanding of the socioeconomic impacts of MPAs underscores the need to invest in extended post-implementation surveys in diverse social and political settings [37,52].

Complementing marine zoning with structural adjustment

It is recognized that MPAs can increase the density of fishermen outside zones that exclude commercial fishing, leading to unsustainable fishing practices and lowered catch rates, thereby potentially negating conservation gains [19,20]. Overcrowding on remaining open fishing grounds was anticipated after the rezoning in Moreton Bay Marine Park [29]. To prevent overcrowding, the Moreton Bay Marine Park Structural Adjustment Package was established to reduce or eliminate displaced fishing effort. The package used a competitive tender process [i.e., reverse auction, 53] to target a predetermined number of licences per fishery for buy-out [29].

Notably, several fishermen in the 2010 survey stated that the remaining fishing grounds were overcrowded after rezoning and that some fishing was unsustainable. These observations suggest that the structural adjustment package did not remove sufficient effort from the Moreton Bay Marine Park. Limiting or preventing the activation, redistribution, or reactivation of fishing effort after a buy-back of licences is paramount to the success of a structural adjustment package. To date, the failure of structural adjustment packages to reduce effort has significantly compromised their efficacy [e.g., 53–55]. Increased involvement of the commercial fishing sector in the development of these programs could make them more effective through better understanding of the complexities surrounding marine spatial planning and, ultimately, enhance support for planning by affected stakeholders [18,47,56].

There is a growing body of literature examining the determinants of temporal and spatial allocation of fishing opportunities [57]. This work, with new simulation approaches to model fishing responses to regulations such as MPAs and changes in target species abundance, provides important insights into how fishing effort can fluctuate in time and space [51,57–59]. Coupling conservation planning processes with dynamic simulation approaches can produce MPAs that are more effective at achieving their goals while also guiding the design of more effective programs for managing displaced fishing effort.

In Australia there is currently an extensive planning process being undertaken by the Commonwealth Department of Sustainability, Environment, Population and Communities (SEWPaC) which will result in additional marine protected areas across Australia's Commonwealth waters. The proposed network of marine reserves was announced on June 14, 2012 and the plans were opened for a 60 day public comment period. Commonwealth waters typically extend from 3 nautical miles from the coast to the outer limit of Australia's Exclusive Economic Zone (EEZ). The first marine bioregional plan was implemented in 2007 for the South-east marine region but was not directly combined with a structural adjustment program [60]; however, in 2005, the Commonwealth government announced the largest structural adjustment package ever offered to the Australian fishing industry of which three of the four targeted fisheries were in the south-east region [61]. Subsequent proposed MPAs in the remaining four Australian marine bioregions could require further structural adjustment packages. This study provides insights into the gaps in knowledge about the socioeconomic impacts of MPAs on fishermen, and emphasises the need for proper design of programs to manage displaced fishing effort, supported by studies of previous programs in Australia and the USA [54,55,61].

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