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Utilising innovative technology to better understand Spanish mackerel spawning aggregations and the protection offered by marine protected areas

Spanish mackerel spawning aggregations and marine protected areas

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Abbreviations

CRFFF ....Coral reef fin fish fishery

CSTFA ....Centre for Sustainable Fisheries and Aquaculture

DoE.....................Department of the Environment

ECSMF...............East Coast Spanish Mackerel Fishery

EPBC..................Environmental Protection and Biodiversity Conservation Act 1999

FSA.....................Fish Spawning Aggregation

GBR....................Great Barrier Reef

GBRMP.............Great Barrier Reef Marine Park

GBRMPA...........Great Barrier Reef Marine Park Authority

GBRWHA..........Great Barrier Reef World Heritage Area

JCU ....James Cook University

QDAFF...............Queensland Department of Agriculture, Fisheries and Forestry

QSIA...................Queensland Seafood Industry Association

ReefMAC ....Reef Management Advisory Committee

Executive Summary

In response to increasing concerns from long-term fishers, and fisheries (QDAFF) and conservation (GBRMPA) managers of the Queensland east coast Spanish mackerel fishery (ECSMF), this project explored and defined historic patterns of exploitation, contemporary patterns of vulnerability and methods for mitigating risk. Project staff from the Centre for Sustainable Tropical Fisheries and Aquaculture (CSTFA) and University of Queensland (UQ) reconstructed a 63 year timeline (1949-2012) of trends in the fishery that allowed contemporary productivity to be compared to historical productivity. During 2010 and 2011 innovative acoustic monitoring techniques were used to identify the current day characteristics of Spanish mackerel aggregating to spawn around a discrete group of well-known spawning reefs off the Townsville coast. These methods were used to identify if the current marine park zoning plan, that includes the protection of some historically important Spanish mackerel spawning reefs, offers any protection to mackerel from fishing. Finally, a management strategy evaluation modelling exercise explored the applicability of spatial and temporal closures as a management tool to reduce catch and/or increase protection of Spanish mackerel aggregating for the purposes of spawning.

Spanish mackerel support important fisheries within Queensland, with a commercial fishery that has operated for in excess of 100 years and an ever important and ever-growing recreational sector. The latest stock assessment of the Queensland east coast Spanish mackerel fishery indicates a fully fished and possibly over-fished status (Campbell et al 2012). This is concerning given only about half of the commercial TAC has been caught in recent years, and contemporary recreational fishery effort and catch is ever increasing. In adding to this stock status concern, anecdote from long-term fishers suggests that spawning aggregations of Spanish mackerel have notably declined in both space and time over a long period of time suggesting the reproductive capacity of the Queensland stock is and has been diminishing over a considerable period of time.

To better understand the vulnerability of Spanish mackerel to fishing, a recent quantitative assessment of commercial logbook data was completed (Tobin et al 2013). Complementary data analyses explored data trends and identified that each year the Queensland east coast Spanish mackerel stock that forms large and predictable spawning aggregations for a very short and defined period (October and November) in a very small well known area of the central Great Barrier Reef (GBR)(Tobin et al 2013) and these aggregations support a disproportional amount of fishing effort and catch. This type of spawning aggregation behaviour exhibited by Spanish mackerel is termed transient aggregation and history demonstrates that is characteristics means species are extremely vulnerable to overexploitation, rapid stock depletion and in severe cases extirpation of local stocks.

The aims of this project are therefore threefold – 1. to quantify the historical changes that have occurred in the spawning aggregation fishery; 2. use acoustic monitoring techniques to understand the aggregating behaviours of spawning Spanish mackerel and whether or not the current Marine Protected Area network of the GBR offers some protection from fishing; and 3. complete an oral history and historical archives search to recreate the performance trends of the ECSMF in order to better understand the state of the contemporary fishery.

The project employed three methods to address the three complementary objectives. To map the historical trends in fishery catch both through space and time, we explored both contemporary logbook data (1988-2012) as well as historic records (1949-2012) sourced through newspaper archives, as well as personal logbooks and oral histories from current and retired fishers. These methods allowed an understanding of trends that have occurred within the spawning aggregation fishery over the extensive history of the fishery. To better understand the aggregating behaviours of Spanish mackerel during their spawning season we used innovative acoustic monitoring technology. Up to thirty-eight acoustic receivers were deployed among 13 reefs where spawning aggregations and fishing have long occurred northeast of Townsville. Across two spawning seasons (2010, 2011) 105 individual Spanish mackerel were tagged with uniquely coded acoustic transmitters that allow individual as well as aggregating behaviours to be detected and described. Finally, a management strategy evaluation was conducted by imposing theoretical closures on contemporary catch data trends to model the impacts of various forms of temporal closure.

The reconstruction of the historical Spanish mackerel fishery clearly identified the Queensland east coast Spanish mackerel fishery has declined through time. The description of extirpation of historically important spawning aggregations from reefs east of Cairns as well as a reduction in size and frequency of Townsville

reef aggregations is particularly worrying. In combination these factors suggest the overall size and thus reproductive potential of the east coast stock has been significantly reduced. The acoustic monitoring component of the project identified a remarkable aggregating behaviour of Spanish mackerel during their annual spawning season. This behaviour included very strong reef and aggregation fidelity for a period of a single lunar month, after which mackerel appeared to disperse from the spawning reefs. Very few between reef movements were detected suggesting a possible strong homing reef ability and behaviour. Such a defined aggregating behaviour suggests that spatial closures are likely to be effective at protecting some Spanish mackerel during spawning. The acoustic monitoring was not able to identify which reef or reefs out of a complex of 13 reefs recognised as important for spawning supported the largest and strongest aggregations. While contemporary fisherman's local ecological knowledge as well as oral history records suggests Rib Reef supports the largest and longest-lasting aggregation of each season, neither the acoustic the tagging nor the contemporary logbook data where able to confirm this. This type of reef importance definition could have provided managers with specific recommendations of spatial closures should that type of management become necessary.

The implications for the commercial fishing industry are significant. The key findings highlight a significant contraction of a fishery resource that has historically supported a considerable level of commercial effort and harvest. Under current stock conditions, management policies and increasing recreational participation, there are no positives regarding the historically important spawning aggregation fishery. Future investment in the commercial sector should be made with upmost caution. The recreational fishery should take particular note of the stock status, historical trends and increasing participation within this fishery and consider the near, medium and long-term consequences. Similarly managers should treat with considerable caution any increases in effort and catch in the Queensland east coast Spanish mackerel fishery while the stock status remains critical. The most difficult question for all stakeholders in how should this finite resource be shared in future years while current trends suggest an increasing desire to access the ECSMF by recreational fishers while traditional commercial fishing seasons and grounds support fewer fishers each year.

In addition to the clear outcomes of this research, we recommend a number of areas for future research, monitoring and management effort. Firstly, a limitation of this research was the inability to define the relative importance of each reef within the spawning complex to Spanish mackerel aggregating to spawn. Research sampling as well as commercial and recreational fishing effort clearly shows that each reef supports an aggregation of mackerel. It may be possible the reef aggregations vary markedly in size and thus spawning potential. Identifying those reefs that are disproportionately important to the aggregating mackerel is paramount should further spatial protection of spawning aggregations of Spanish mackerel be considered necessary. Secondly, the analysis of commercial fishery data through the extensive history of the Spanish mackerel fishery clearly identifies a fishery in continual decline in catch, effort and fisher participation. In contrast, participation in the recreational fishery continues to increase. Any future research, monitoring and management needs to explicitly consider the characteristics of the recreational fishery which in the current day is likely to exceed commercial effort and catch. Contemporary and robust estimates of recreational catch are urgently needed. Further monitoring efforts should also include the identification of fishing effort and catch "hotspots" of the recreational fishery. As has been demonstrated by Tobin et al (2013) and the outputs from this project, Spanish mackerel are an obligate transient aggregator and this behaviour suggests temporal and/or spatial closures could be an effective effort and catch constraining management tool should that type of management intervention be required. When and where effort and catch peaks for Spanish mackerel is likely to be indicative of aggregating behaviours that render Spanish mackerel highly vulnerable to fishing. This knowledge could however also assist managing future catch and effort through spatial and/or temporal closures. Finally, as the participation and catch trends within the commercial and recreational fishing sectors appear negatively correlated since the mid-2000s, methods for managing this changing allocation of the resource need to be considered.

Keywords

Spanish mackerel, spawning aggregation, marine protected area, Great Barrier Reef, acoustic monitoring, oral histories.

Introduction

Spanish mackerel is an important commercial and recreational species with a combined total catch of 650t taken from Queensland east coast waters annually in recent years (Campbell et al 2012). The ecology of the Queensland east coast Spanish mackerel stock includes a strong seasonal and predictable migratory behaviour that allows fishers to efficiently target Spanish mackerel as aggregations of fish move through or temporarily reside in particular regions along the east coast (Tobin & Mapleston 2004). For the commercial sector of the fishery, a spatially discrete group of inner lagoon reefs northeast of Townsville (approximately 18^0 S) are disproportionately important for annual effort and catch, where historically one-third of the annual commercial catch is landed (Tobin et al 2013). Further, the large majority of this catch is taken during the well-defined and temporally discrete spawning season that is wholly constrained within the months of October and November of each year. In contrast, most of the annual recreational harvest is taken from south-eastern Queensland waters (between 25 and 28 degrees S) over a longer period, spanning January to June of each year, as mackerel disperse south following the spring spawning season in northern waters (Tobin & Mapleston, 2004).

Early this decade, several stock assessments (O'Neill & McPherson, 2001; Welch et al 2002) and a management strategy evaluation (Hoyle 2002) of the fishery collectively indicated the fishery was at that time likely fully exploited and that the spawning biomass was likely low. Each report encouraged a precautionary approach to the management of the east coast fishery, and specifically cautioned against any increase in harvesting from then current levels of around 1100t annually. The then Reef Management Advisory Committee (ReefMAC) and Queensland Fisheries Service (now Fisheries Queensland (FQ), Queensland Department of Agriculture, Forestry and Fisheries – QDAFF) responded in 2003 by amending the management arrangements for the ECSMF to remove as much latent effort as possible from both the recreational and commercial sectors. Latent effort was reduced by a reduction of the in-possession limit for recreational anglers from 10 to 3 fish and introducing a Total Allowable Catch (559t) for the commercial fishery.

In July 2004, soon after FQ reviewed and changed the traditional fisheries management arrangements for Queensland east coast Spanish mackerel, the Great Barrier Reef Marine Park Authority (GBRMPA) introduced a revised zoning plan for the Great Barrier Reef World Heritage Area via the Representative Areas Program (RAP). The RAP effectively increased the proportion of offshore reefs designated as no-fishing zones from 21 to 33 percent. Despite demonstrated reliance of the annual commercial Spanish mackerel harvest on fishing seasonal aggregations on primary spawning reefs (Tobin 2000; Tobin and Mapleston, 2004), the RAP did not rezone any of the five primary spawning and hence fishing reefs (namely Bramble, Rib, John Brewer, Lodestone and Keeper Reefs) as no-fishing, though did re-zone two secondary spawning reefs (namely Kelso and Helix Reefs) as no-fishing. A subsequent fish spawning aggregation (FSA) workshop convened by the GBRMPA, has however highlighted the need for research into the impacts of fishing on Spanish mackerel spawning aggregations (Russell & Pears, 2007). In addition Tobin et al (2013) recently assessed all lines fisheries within the GBRMP and defined Spanish mackerel as the most vulnerable line targeted finfish to fishing during spawning and concluding Spanish mackerel is an obligate transient aggregating species. Transient aggregating species form few but very large and predictable aggregations, that once discovered by fishers can be quickly overexploited (Sadovy & Domeier 2005).

Overshadowing this history is the now common anecdote, mostly from commercial fishers, reporting a gradual contraction of the spatial and temporal extent of spawning aggregations of east coast Spanish mackerel. Early research by Munro (1942) formally defined the spawning areas and timing for the east coast stock, despite the fishery occurring for at least 20 prior years. Continued exploitation over the next 30 odd years resulted in some fishers and researchers expressing concern about the frequency and duration of spawning aggregations (McPherson 2007). Given this LEK of fishers has never been formally accumulated and analysed; an opportunity exists to explore these reported phenomenon. Without considering an entire history of a fishery, contemporary management may be ineffective as shifting baselines bias estimations and perceptions of fishery health and productivity (Thurstan et al 2010).

Contemporary fishers also report that with each passing year, more search time and area coverage is required to find mackerel and maintain commercial levels of catch. Since 2004, the reduction of latent effort in the fishery as well as the introduction of RAP has been followed by relatively stable catches by recreational fishers and a precipitous decline in commercial harvest. As a result, the harvest allocation has moved from a position of relatively even split between commercial and recreational sectors late last century, to current day dominance by the recreational fishery (67% of annual landings). This “changed face” of the fishery now presents a difficult problem for QDAFF and GBRMP managers in light of the outputs from the most recent stock assessment. This assessment, with improved input data, again concluded that the east coast fishery is fully exploited (although now at the 650t annual harvest level) and any increase in commercial and/or recreational landings would likely push the fishery into overfished status (Campbell et al, 2012). The quandary presenting itself is how to appropriately manage this fishery into a future, which likely contains a desire for increased access and effort from the recreational fishing sector as well as a desire of the commercial fishing fleet to catch their allocated quota that is in recent years less than half caught.

A fishery in the fully fished state needs to be re-built in order to move stock status away from the knife edge of overfished status. Considerations of how to achieve such a re-building goal may include a range of options including re-evaluating recreational and commercial fishery harvest levels (ie global fishery TAC), and spatial and/or temporal closure protection of recognized Spanish mackerel aggregation areas (both within and outside of the spawning season).

The proposed project will focus on better understanding the use of primary and secondary spawning reefs by Spanish mackerel during their recognized spawning period. Of particular importance is the need to better understand the effects of historical and current day concentrated fishing on aggregations of spawning and pre-spawning mackerel. Given the current status of the Spanish mackerel stock, appropriate management decisions can only be made by understanding how Spanish mackerel use the spatially discrete spawning reefs within their temporally discrete spawning period, the time at which they are most vulnerable to fishing pressures (Tobin, 2013). If aggregating mackerel spend a considerable amount of time within certain reefs than others, some further extension of spatial closures may be required. Conversely, should mackerel roam relatively freely amongst the reefs of the spawning complex, temporal closure protection may be a more applicable management consideration.

Objectives

1. Document and describe temporal and spatial trends of spawning aggregations throughout the recent history of the fishery.

2. Quantify the potential benefits of marine protected areas to spawning aggregations.

3. Conduct an MSE to quantify the benefit(s) of spatial and / or temporal closures as management options for Spanish mackerel.

Methodology

Documenting the temporal and spatial trends of the spawning aggregation fishery

The Queensland east coast Spanish mackerel fishery operates is all waters off the east coast from the waters of Torres Strait in the north down to the southern border of Queensland (Figure 1). The historically important spawning aggregation fishery is concentrated within latitude 18 in the central section of the Great Barrier Reef (GBR). The project objectives and thus methods repeatedly focus on and reference this small area.

Contemporary commercial logbook data

Contemporary commercial logbook data (years 1988 to 2011, inclusive) was sourced from Fisheries Queensland. The data included daily catch and effort records for each licence, with individual fisher (licence) anonymity protected by the utility of unique identifiers rather than boat marks or fisher name. Daily catch is recorded within 0.5 degree latitudinal bands that allows for some robust spatial and temporal trends to be explored however, identifying catch and effort to individual reefs within the spawning complex is not possible.

The contemporary logbook data was initially summarised to identify state-wide trends in catch and effort. Space was broadly considered though purposely highlights latitude 18 as the significant effort and catch location for the fishery. Latitude 18 was compared against the cumulative data of all latitudes north (latitudes 11 through to 17 grouped) and all latitudes south (latitudes 19 through to 27 grouped). Regression analysis was used to identify trends (increasing, decreasing or stable) in the CFISH time series of catch (tonnes) and effort (licences) by expressing each spatial factor (northern latitudes, latitude 18, southern latitudes) as a proportion of total annual catch.

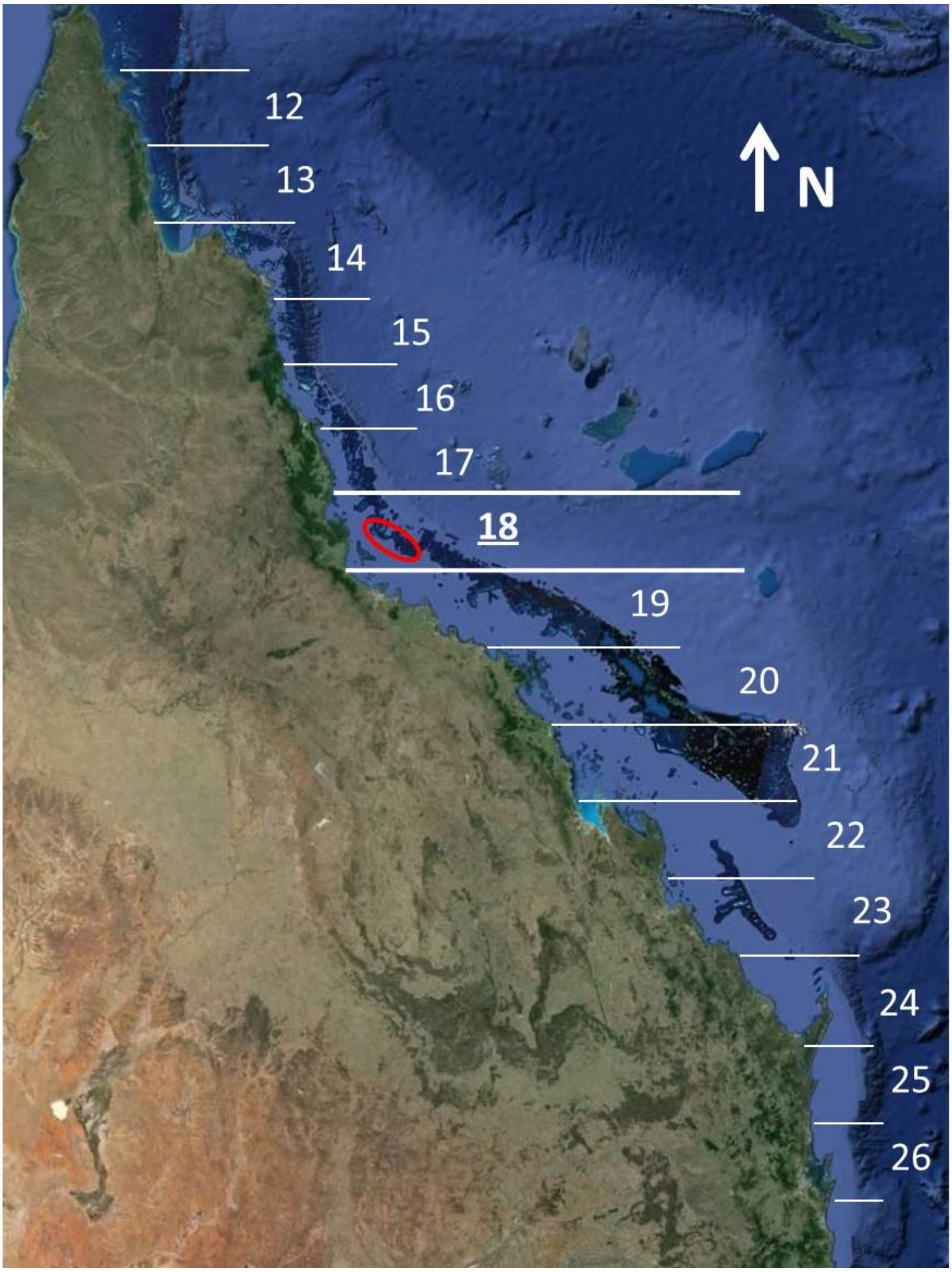
For each latitude group (North, Townsville and South) trends in the proportion of annual catch landed during spawning months as opposed to non-spawning months was similarly investigated by linear regression. The non-spawning period included calendar months January to September (inclusive) while the spawning period included calendar months October to December (inclusive) in following the analyses of Tobin et al (2013).

To better explore the potential for changes in catch and/or effort in the historical important spawning reef complex of latitude 18, the database was filtered to remove licences that demonstrated infrequent effort and catch. Active licences were identified as those that had at least 5 years of at least 1,000 kilograms per year within the 1988 to 2011 time period. Regression analysis was again used to explore the relative contribution of spawning season months to annual catch and effort.

Historical data

In total, 29 individual semi-structured interviews were conducted with active and retired fishers that had targeted the spawning fishery. Fishers were initially identified by a list compiled from discussion with fishery scientists and then by snowball sampling following the initial interviews. Snowball sampling relies on interviewees identifying prospective future participations, and as commercial fishing communities are reasonable small, snowball sampling can be a very effective strategy. The interview was developed from previous research conducted by Saenz-Arroyo et al. (2005), O'Neill and Leigh (2006) and Daw et al. (2011). The complete survey included questions on abundance and catches, gear and technology, location and factors causing change (see Appendix C). The sample of fishers was categorized into sub-samples such as period fisher commenced fishing to examine differences in perceptions of the state of the fishery. For the present report questions on catch variability included catch on a "good", "average" and "poor" day during fisher's career, i.e. when they first began fishing, significant events during their career and most recent fishing experiences. Fishers were also asked to describe whether they perceived spawning abundance of Spanish mackerel to be increasing, decreasing or stable. Catches were generally reported as number of fish per day and effort as number of hours fished. Regression analysis was used to identify trends in the fisher's time series of catch (fish/day) and effort (number of vessels per reef) per spatial factor (Townsville aggregation, Cairns aggregation).

Figure 1. The Queensland east coast with bands of latitude indicated. The historically important spawning aggregation fishery is largely confined within the single band of latitude 18 degrees south. The red circle highlights the small group of inner shelf coral reefs where aggregations occur and are fished each spring.



Quantifying the benefits of marine protected areas to mackerel aggregating to spawn

Acoustic monitoring

Acoustic monitoring equipment (Vemco, Canada) and techniques were used to observe the behaviour of Spanish mackerel during their spring spawning season within a group of reefs northeast of Townsville known as the primary spawning reef complex for the Australian east coast stock. Acoustic telemetry equipment consisted of an omnidirectional hydrophone (or receiver) that is capable of recording the presence of hundreds of fish tagged with uniquely identifiable acoustic transmitters (Heupel et al. 2006). To observe Spanish mackerel, this project utilised Vemco VR2W acoustic receivers and V9 acoustic transmitters with a 60 to 120 second random delay giving a tag life of 152 days; a time step that would exceed the known period of spawning (October and November; McPherson, 1993).

In September 2010, twenty Vemco VR2W acoustic receivers were deployed amongst 9 reefs from within the primary spawning reef complex northeast of Townsville. The nine reefs spanned a maximum distance of 42 nautical miles and included 3 reefs closed to fishing and 6 reefs where fishing is permitted (Figure 2A). The receivers were retrieved in early 2011, although 3 were lost due to the passage of severe Tropical Cyclone Yasi (February 2nd 2011). In August 2011, thirty-eight Vemco VR2W acoustic receivers were deployed amongst 13 reefs spanning a maximum distance of 67 nautical miles (Figure 2B). The receivers were deployed with a preference for the north-western aspects of each reef, on the advice and experience of long-term fishers that these aspects are the within reef locations where Spanish mackerel are most likely to aggregate and thus targeted by fishing. Receivers were fixed at depths of approximately 15 metres on the reef slope in positions that allowed for unobstructed "listening" towards the deeper waters abutting reef edges where Spanish mackerel aggregate (Figure 3).

Receiver range testing was conducted at Rib Reef in July 2011 by redeploying a receiver in the northeast location and anchoring in place three acoustic transmitters at distances of 130, 190 and 310 metres. The deployment was maintained for a 24 hour period and then retrieved. The effect of distance, tide and time (day/night) on detection efficiency was tested by generalised linear model.

Modified commercial apparatus was used to capture mackerel and ensure capture and handling times were as short as possible. In place of the usual ganged hooks used by commercial fishers, a single hook rig (Mustad 4225D, size 10/0) was used and the hook barb either squashed flat or filled off. Hooks were rigged on approximately 30cm of multi-strand wire and either a lead or chrome wog head added to mimic the standard commercial apparatus. Rigs were baited with garfish (*Hemirhamphus robusta*)(Figure 4) and fished from deck winches allowed most hooked mackerel to be winched to the side of the research vessel and tag and released within 90 seconds. Fish were tagged with V9 acoustic transmitters while in the water. The research vessel maintained a continuous speed of approximately 4 knots so that water continued to flow over the gills of each mackerel while it was tagged. The V9 transmitters were fitted with end caps that were wired to Domeier umbrella tag heads with approximately 150mm of stainless steel wire (Figure 5). This method allowed for the umbrella tag head to be placed within the dorsal musculature while the transmitter trailed externally (Figure 6). Dependent on fish behaviour beside the tagging vessel, some fish shook hooks free, some fish were de-hooked and some were released by cutting the hook with bolt cutters. Any physically damaged and/or bleeding fish were not tagged (advice Rik Buckworth, PI FRDC Project 2007/033). The weight of each fish tagged was estimated.

During the tagging trips, a small sub-sample of captured mackerel was retained in some locations to determine reproductive stage and thus activity. Additional samples were obtained opportunistically from commercial fishers who may have been fishing on the same reef. Gonad activity was assessed macroscopically following the methods of Mackie and Lewis (2001).

Data analysis

Data from the receivers was pooled at the reef level. Fish were considered present at a reef when one or more detection were recorded within a 24 hour time period. Although it is common within acoustic monitoring studies to reject single detections on the basis that they could be erroneous detections caused by "collision" of two or more separate tags signals, all of the single signal detects in this study occurred when only one fish was present at the receiver across a substantial time period and thus were considered real detections. Presence plots were used to identify the daily presence patterns of individual fish among the reefs that made up the arrays.

Diurnal patterns were investigated by chi-square contingency tables used to explore day and night detection data among reefs for each year. Reefs with less than 50 detections per year were omitted from the analysis.

Residency was calculated at two spatial levels: firstly residency within the array, and secondly residency at the reef of initial capture, tag and release. Residency within the monitored area was calculated for each individual by expressing the number of days detected as a proportion of each individuals monitored period. The monitor period was defined by the first and last days of detection for each mackerel. Residency at reef of initial capture was similarly calculated by expressing the number of days present at the reef of initial capture as a proportion of the total numbers of days detected. The effect of year and reef management status on residency was tested with two-factor analysis of variance.

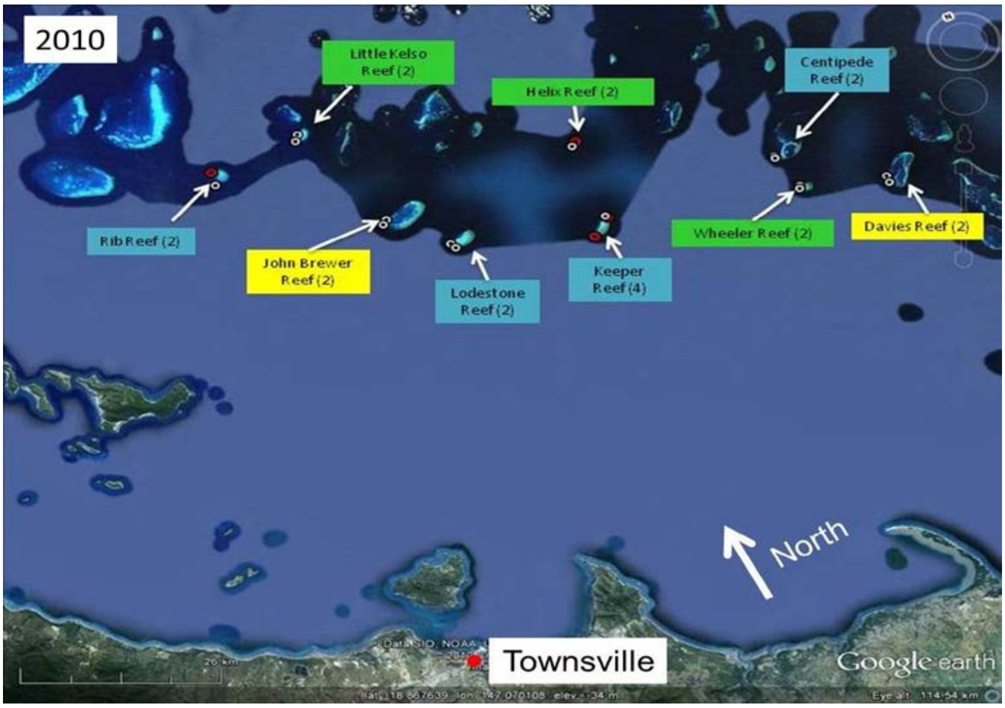
Roaming was calculated by expressing the number of reefs on which each mackerel was detected as a proportion of the all reefs included in the arrays: 9 reefs in 2010, 13 reefs in 2011. The effect of management status on roaming was examined by t-test for both years.

The numbers of days aggregations of mackerel persisted at a reef was determined using Kaplan Meier estimator. Kaplan Meier estimates the persistence time of an aggregation and in this application was utilised to estimate the day's duration of an aggregation of Spanish mackerel at a reef. Three metrics were estimated for each aggregation and include minimum, maximum and average number of days present. In 2011, four tagging events provided data for estimating aggregation persistence; a group of 8 mackerel tagged at Wheeler Reef on 21st September, a group of 4 mackerel tagged at Helix Reef on the 6th October, a group of 9 mackerel tagged at Lodestone Reef on the 7th October, and a second group of 4 fish tagged at Helix Reef on the 30th October. The relationship between the three metrics and lunar phase was then explored by linear regression where the number of days prior to the new moon was an independent factor that may predict aggregation strength.

Movements within the array were plotted in Google Earth, and the observed directions and distances of movement compared against all possible combination of directions and distances available within the array. To test whether mackerel were more likely to move among closed reefs than open reefs, the proportion of movements among the different management zones was tested by Fisher's Exact tests.

Figure 2 The location of acoustic receivers in 2010 (a) and 2011 (b) amongst the primary spawning reefs northeast of Townsville. Receivers were deployed to ensure coverage of both fishing (yellow and blue reefs) and no-fishing (green) reefs. The four receivers highlighted by the red circles in the 2010 deployment were lost during TC Yasi (Feb 2011).

a.



b.

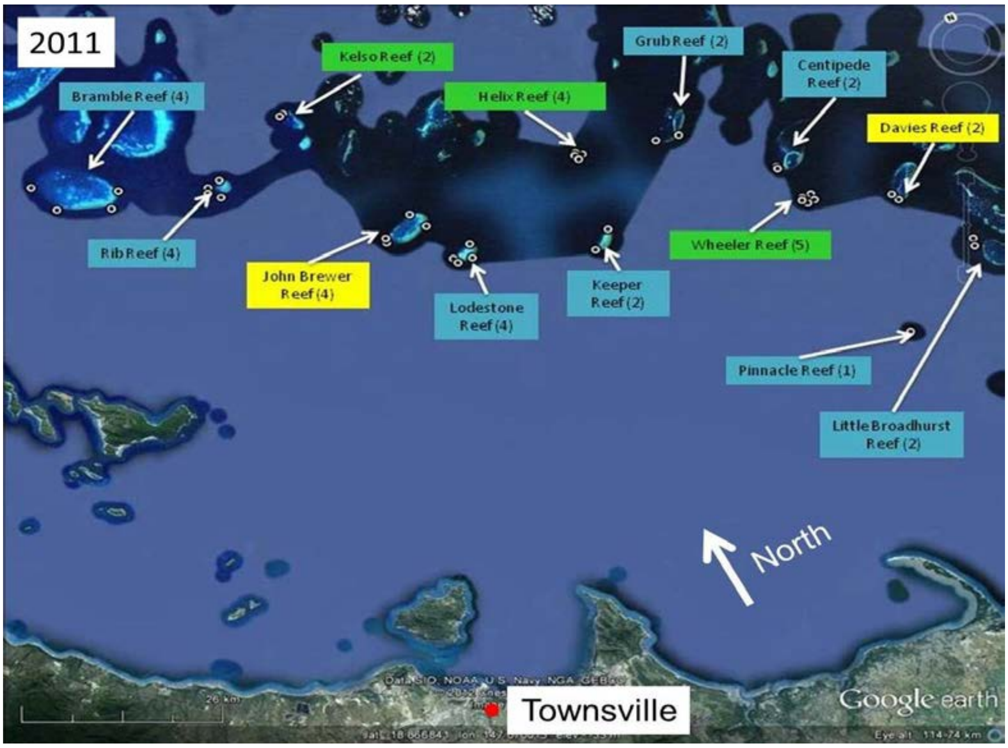


Figure 3 An example of a receiver *in situ* anchored on the reef crest to enable unobstructed "listening" to the deeper waters abutting the reef where Spanish mackerel are known to aggregate.

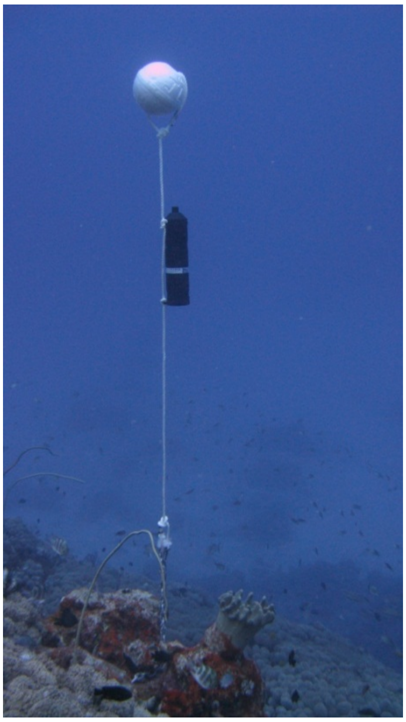


Figure 4 A garfish rigged on a modified commercial mackerel rig where a single barbless 10/0 hook was used in place of the standard gang of two 10/0 hooks

Figure 5 Domeier umbrella tag heads were used for intramuscular placement, while allowing transmitters to be trailed externally via approximately 50mm.

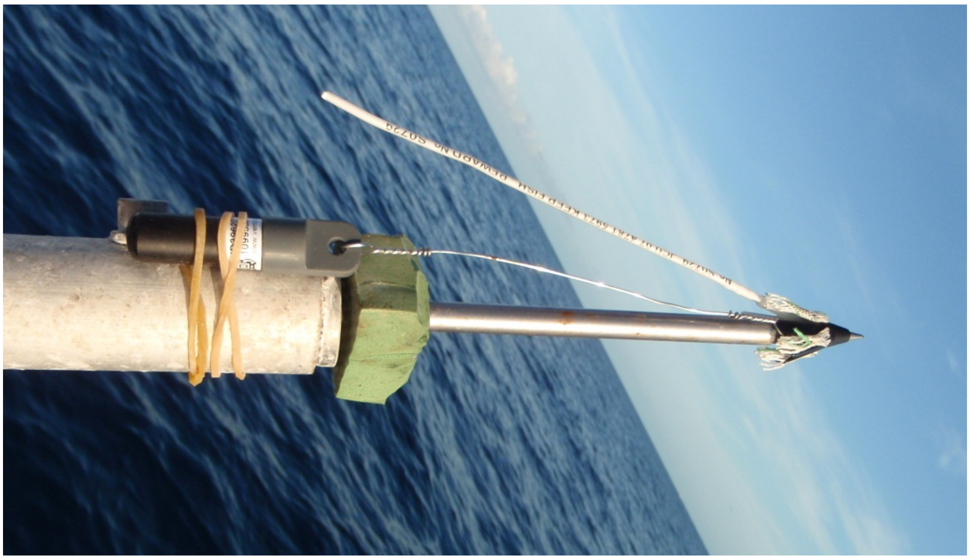


Figure 6 Captured mackerel were tagged in the dorsal musculature so that the V9 acoustic transmitters trailed the fish from the shoulder area.

Management strategy evaluation of the benefits of spatial and/or temporal closures

Temporal spawning closures currently apply to the CRFFF, though not to the ECSMF. Temporal closures for the CRFFF were first introduced in 2004 and included three discrete closures around the new moon periods in October, November and December of each year. The closures were initially 3 x 9 days in length, though following a review in 2008 were reduced to 2 x 5 day closures with the December closure removed completely. The introduction of the closures as a management tool was enthusiastically debated at the time by the ReefMAC as their purpose and value was questioned when an complexity of management was already in place including a vast MPA network, a TACC, minimum legal size limits and effort restrictions (fishing platform length and number limits, hook limits, etc). Interestingly, although there were no formal stock or spawning aggregation assessments available to better inform debate, anecdote and catch figures clearly identified Spanish mackerel as the species most vulnerable to exploitation during spawning when compared with all other GBR associated and commercially targeted fishes. Further, it was only until recent years that vulnerability to fishing during spawning has been explicitly considered by researchers (see Tobin et al 2009; Tobin et al 2013). Regardless, it is important to note that the introduction of temporal spawning closures to the CRFFF in 2004 was without any specific management objective such as maintaining reproduction potential.

Spatial closures are abundant throughout the GBR though are in place primary for ecological protection (McCook et al 2010) and not for fisheries sustainability goals such as maximising the survival of adult fish or maintaining egg production. That said, a report on the GBR zoning plan makes specific mention of a number of reef closures that occurred during the 2004 re-zoning in part due to knowledge that aggregations of spawning Spanish mackerel do occur at these reefs (GBRMPA 2005), though the report contains no further information to describe how this information was derived. Of the primary reef spawning complex (Figure 2), Kelso and Helix Reefs were closed to fishing in 2004, and both supported significant levels of Spanish mackerel fishing before closure. The

In light of this history of temporal and spatial closures, this component of the project was tasked with investigating the efficacy of both spatial and temporal closures in offering protection to aggregations of Spanish mackerel that have formed for the purpose of spawning. To ensure the modelling completed in the MSE was the most robust and applicable to management needs as possible, the structure of the MSE modelling was discussed at the final project workshop. The likely components of this MSE exercise were discussed in a workshop setting with both QDAFF and GBRMPA managers to ensure the outputs were useful and relevant to all stakeholders needs. The final project workshop was held after the completion of the second year of acoustic research so that outcomes from that work could be used to inform those factors most useful to MSE model. In addition preliminary MSE outputs were also provided to workshop participants to better inform the discussion.

Modelling SPATIAL CLOSURE EFFECTIVENESS - Movements among reefs are too few and infrequent for modelling to consider spatial management scenarios any more than the assumption that closing 1 of the 10 spawning reefs will protect 10% of spawning biomass from fishing. The acoustic monitoring data demonstrated significant residency of mackerel to the reef of initial tagging, though once leaving this reef mackerel tended to disperse from the spawning reef complex. This result is very encouraging of the ability of the current marine park zoning network to offer protection to aggregations of Spanish mackerel from fishing. However, in the absence of any data that identifies reef-specific abundance during the spawning season, modelling spatial closures to quantify protection offered to aggregations of Spanish mackerel will remain simplistic. Commercial logbook data does not include fine enough spatial reporting to be used as a proxy for ranking the importance of the individual reefs within the spawning reef complex to the fishery (assuming historic catch volumes are indicative of aggregation size).

Modelling TEMPORAL CLOSURE EFFECTIVENESS – There is strong evidence that an aggregation will persist on a reef for a lunar cycle with individual mackerel within an aggregation on a reef dispersing from that aggregation and reef around the full moon. This behaviour suggests that temporal closures could also be a useful management tool for the Spanish mackerel line fishery. With the existing temporal spawning closures that apply to the Reef Line Fishery, we applied the historic 3 x 9 day closures and contemporary 2 x 5 day closures to the catch of Spanish mackerel to estimate the impact on landed catch. The outputs identify the volume of catch that would not be available to be taken, if temporal closures were to be used as a management tool in this fishery. These models run prior to the final project workshop (Sep 2012) identified that if significant reduction in catch are warranted, temporal closures that mirror either the 5 or 9 day closures would likely be insufficient. Thus we used a general linear model to estimate the effect of three different temporal closure options including –

a. calendar month October,
b. calendar month November, and
c. calendar month October and November.

on the catch that would be landed by the fishery within the three distinct spatial areas of the fishery. The model considered the same three regions as Chapter 2 – north (all latitudes north of latitude 18 grouped; latitude 18; and south (all latitudes south of latitude 18 grouped). The data modelled included catches from 2005 to 2011 as the effort and catch characteristics of the fishery changed post-2004 following the introduction of quota and extended spatial management.

Results

Documenting the temporal and spatial trends of the spawning aggregation fishery

State wide trends

Annual state wide catch volumes have varied between a low of 221 t in 2007 and a high of 732t in 2002 (Figure 7A). Similarly, the number of fishers accessing and landing Spanish mackerel has varied markedly with a low of 186 fishers in 2006 and a high of 658 fishers in 2002 (Figure 7B). Precipitous drops in catch and licence activity followed the significant management changes introduced in July 2004 that included the extension of no fishing zones within the GBRMP, and the introduction of a total allowable commercial catch (TACC) system for the fishery.

In considering state-wide annual catch, the proportion taken from latitude 18 declined throughout the time series, though the trend was not significant ($F_{1,22} = 2.66$; $p = 0.12$); the southern latitudes significantly increased its contribution ($F_{1,22} = 4.32$; $p = 0.04$), while the northern latitudes annual catch contributions remained unchanged ($F_{1,22} = 0.02$; $p = 0.89$)(Figure 7A).

When the number of active licences were considered, the proportion of licences accessing latitude 18 remained stable throughout the time series ($F_{1,22} = 1.16$; $p = 0.29$); the proportion of active licences decreased significantly through time in the southern latitudes ($F_{1,22} = 52.6$; $p = 0.000$) and the proportion of active licences increased significantly through time in northern latitudes ($F_{1,22} = 135.2$; $p = 0.000$)(Figure 7B).

Within latitude trends

The relative volume of catch taken within spawning months as compared with non-spawning months varied among locations. For the northern latitudes between 15 and 36% of annual catch was taken during the spawning season (Figure 8A); for latitude 18 between 56 and 90% of annual catch was taken during the spawning season (Figure 8B); and for southern latitudes between 6 and 27% of annual catch was taken during the spawning season (Figure 8C). The relative contribution of spawning season catch to annual catch throughout the time series of data also varied among locations. Significant decreases in the contribution of spawning season months to annual catch was present in both northern latitudes ($F_{1,22} = 29.3$; $p = 0.000$) and latitude 18 ($F_{1,22} = 4.7$; $p = 0.04$)(Figure 8D).

Latitude 18 trends

When only active fisher data was considered, significant trends in the performance of the spawning aggregation fishery were also evident. The proportion of annual catch taken within spawning months as compared with non-spawning months demonstrated a significant decline through time ($F_{1,22} = 6.4$; $p = 0.02$)(Figure 9A). Similarly the proportion of active licences accessing the spawning fishery significantly decreased through time ($F_{1,22} = 18.7$; $p = 0.000$)(Figure 9B). However these trends may be a simple reflection of the fact that a reduction in active licences will result in a reduction in catch ($F_{1,22} = 6.40$; $p = 0.019$)(Figure 9C). This suggests that active vessels fish to capacity regardless of the number of vessels present, and that fewer vessels don't result in more catch per vessel.

Figure 7 Contemporary commercial fishery logbook data identifying annual catch (A) and effort (B) trends in the Queensland east coast Spanish mackerel fishery. Data is summarised to demonstrate the relative contribution (dashed trend line) of the single band of latitude of 180 S where the historically important spawning aggregation fishery occurs, compared against all latitudes north and all latitudes south.

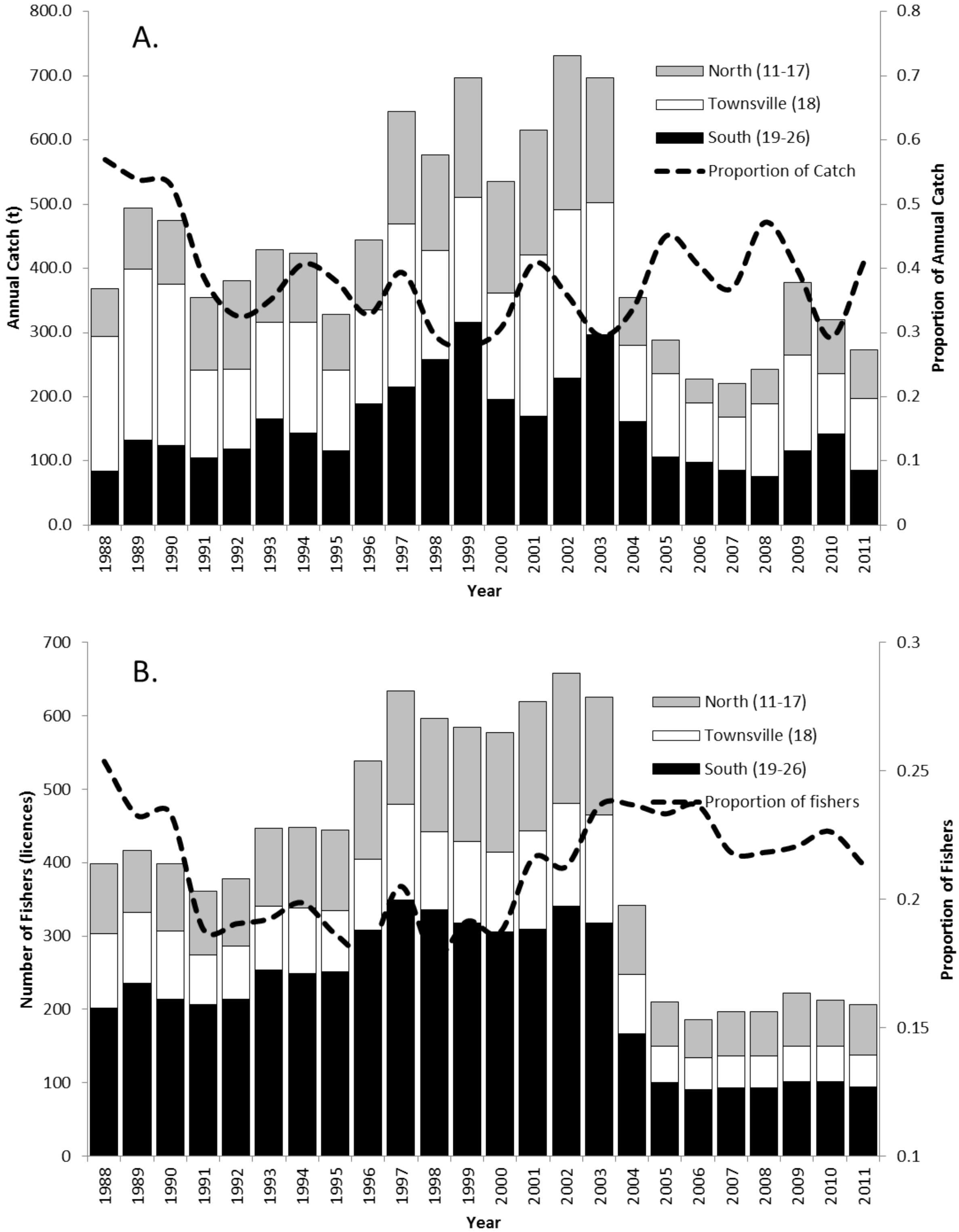


Figure 8 Contemporary commercial fishery logbook data identifying volumes of catch taken during the spawning months (shaded) compared with non-spawning months (not shaded) in A. northern latitudes (11-17), B. latitude 18 and C. southern latitudes 19-26). The relationship between volume of catch landed in spawning season and volume of catch landed in the non-spawning season is shown in D with regression analysis identifying trends occurring through time.

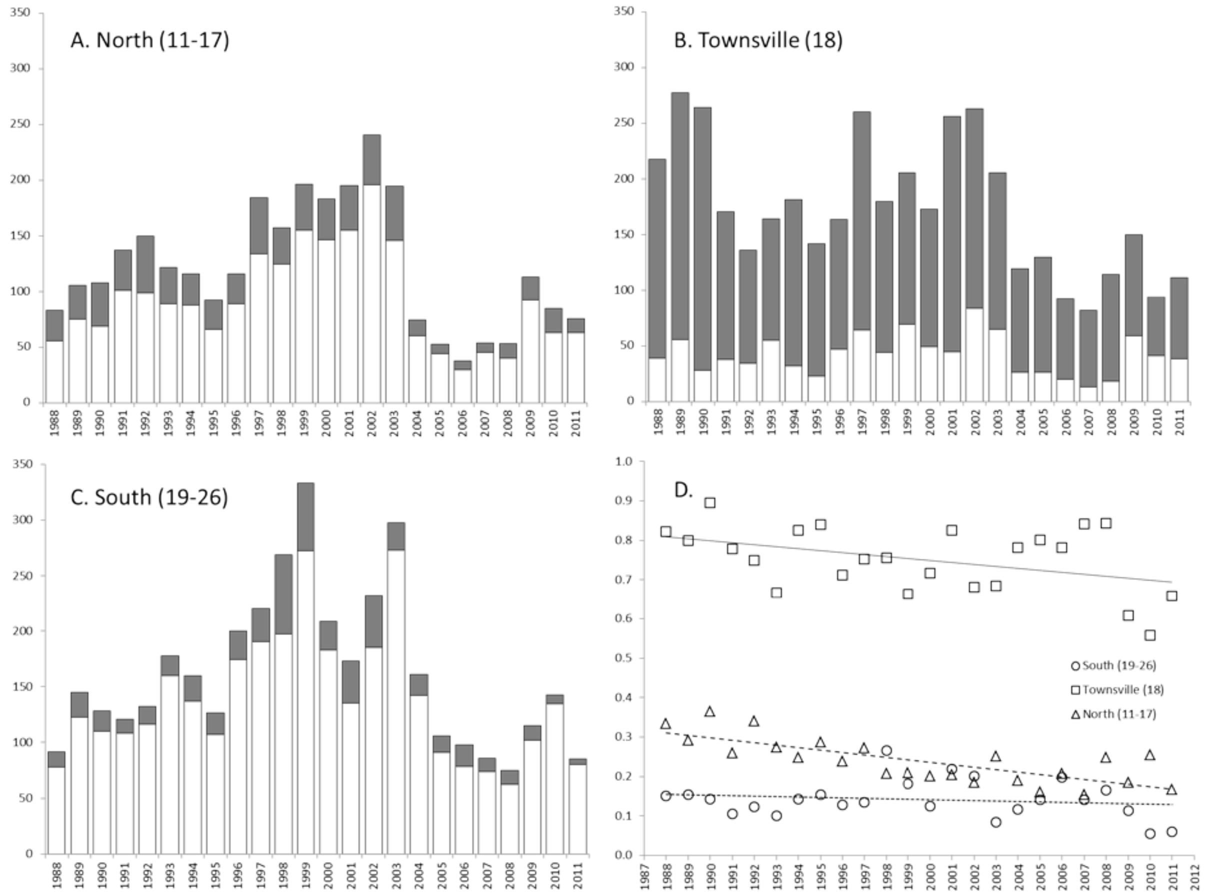
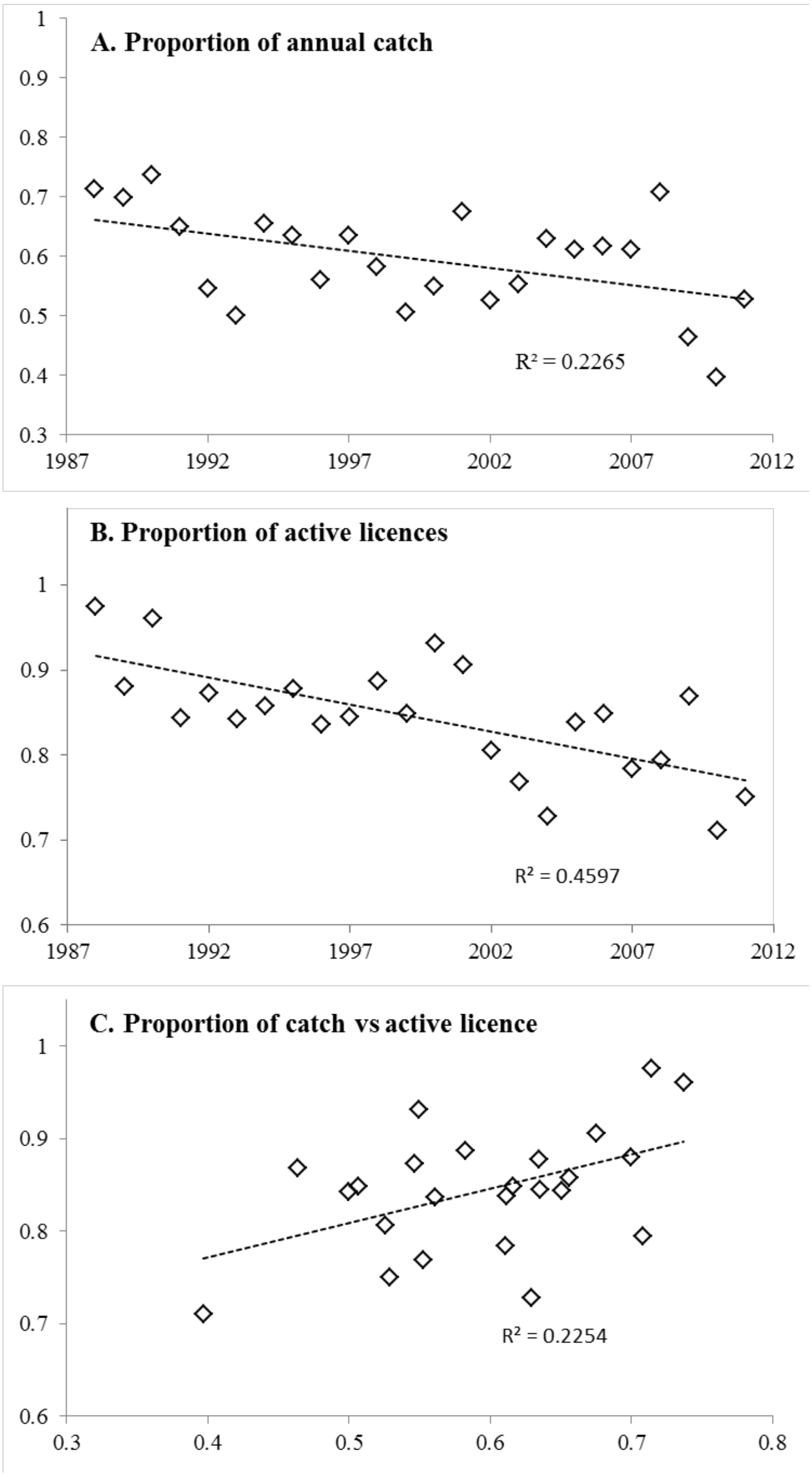


Figure 9 Active fisher data from contemporary commercial fishery logbooks demonstrated - A. a significant decrease in the relative proportion of annual catch taken from within the spawning season as compared to the non-spawning season; B. a significant decrease in the number of active licences fishing during the spawning season compared with the non-spawning season; and C. the positive correlation present between the number of active licences and proportion of annual catch taken.



Oral histories

Fishers from a range of age groups (Figure 10A) were interviewed however the young fisher category was excluded because no fishers of this age category participate in the spawning fishery. The participants had between 6 and 48 years of experience (Figure 10B); 35% of the fishers commenced in the early period (1949-1971); and 65% commenced in the mid period, 1972-1991 (Figure 10C). The decade with most participation of the sample is the 1980s, 94%, and the proportion of participation in the fishery decreased to 34% by 2012 (Figure 10D).

Overall, the vast majority (72%) of respondents cited a decline being observed in the abundance of fish in the spawning aggregation over time (Figure 11A). Further analysis revealed similar perceptions of decrease held by both sub-sample groups, the time period fishers commenced fishing (72% early and 73% mid), as no significant difference in perception between fisher groups was observed: $F(1,2)=2.579$, $p=0.2495$ (Figure 11B). From the respondents who perceived a decrease, 62% considered the rate of decline to be occurring gradually over time (Figure 11C). The impact of prawn trawling was the most frequent reason cited by fishers for the decline of the Spanish mackerel population (Figure 11D). Of secondary significance was increased fishing effort. A range of other factors was cited as causal for the decline of the spawning aggregation including recreational exploitation and coastal development.

No significant effect was detected for the correlation of the best catch rate of with the year the fisher recollects (with a regression line shown $r^2 = 0.019$, $p>0.001$) (Figure 12A). Similarly a regression analysis of the longest duration of best catch fishers recollected versus year demonstrated no significant effect ($r^2 = 0.059$, $p>0.001$) (Figure 12B).

A cumulative regression analysis of fisher's quantitative accounts of good and average catch rates exhibits a stable trend in catch rate respectively for the Townsville fishery ($r^2=0.0267$, $p=0.1435$, $r^2=0.01426$, r2=0.01426) (Figure 13A, 13C). This differs significantly from the Cairns fishery where a regression of the year against good catch rate suggests a decrease but not statistically significant ($r^2=0.4975$, $p=0.0766$, Figure 13B). However the average catch rate declined so significantly ($r^2=0.6158$, $p=0.0366$) that fishers ceased fishing this aggregation from 1998 (Figure 13D).

Figure 10 Characteristics of the fishers interviewed: (A) The age range of fishers at the time of the interview (2012), (B) fishing experience, (C) the time period fishers commenced targeting the spawning fishery and (D) number fished per decade. Data is summarised to demonstrate that expert knowledge extends back a broad temporal scale and that fishers interviewed have long-term experience of the spawning fishery.

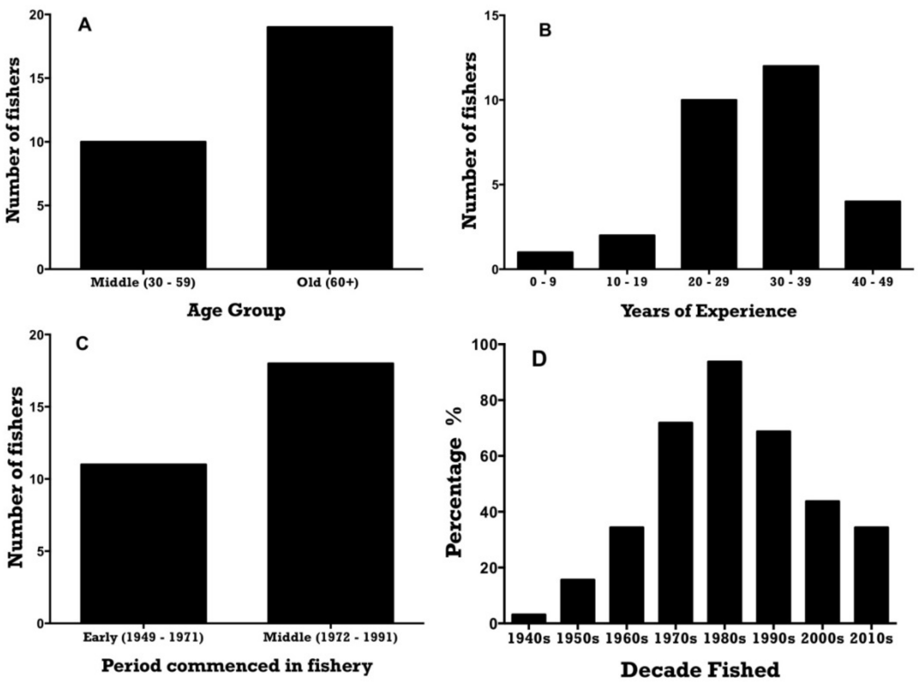


Figure 11 Fishers perceptions of change to the abundance of mackerel during spawning over time: (A) perception of changes in abundance over time by all fishers interviewed (B) the effect of the time period fishers commenced targeting the spawning fishery on the proportion of fishers who stated that the abundance has increased, decreased or remained stable, (C) the proportion of fishermen who reported the decline occurred rapidly or gradually and (D) reasons given by fishers for the decrease in Spanish mackerel abundance during spawning since they commenced fishing.

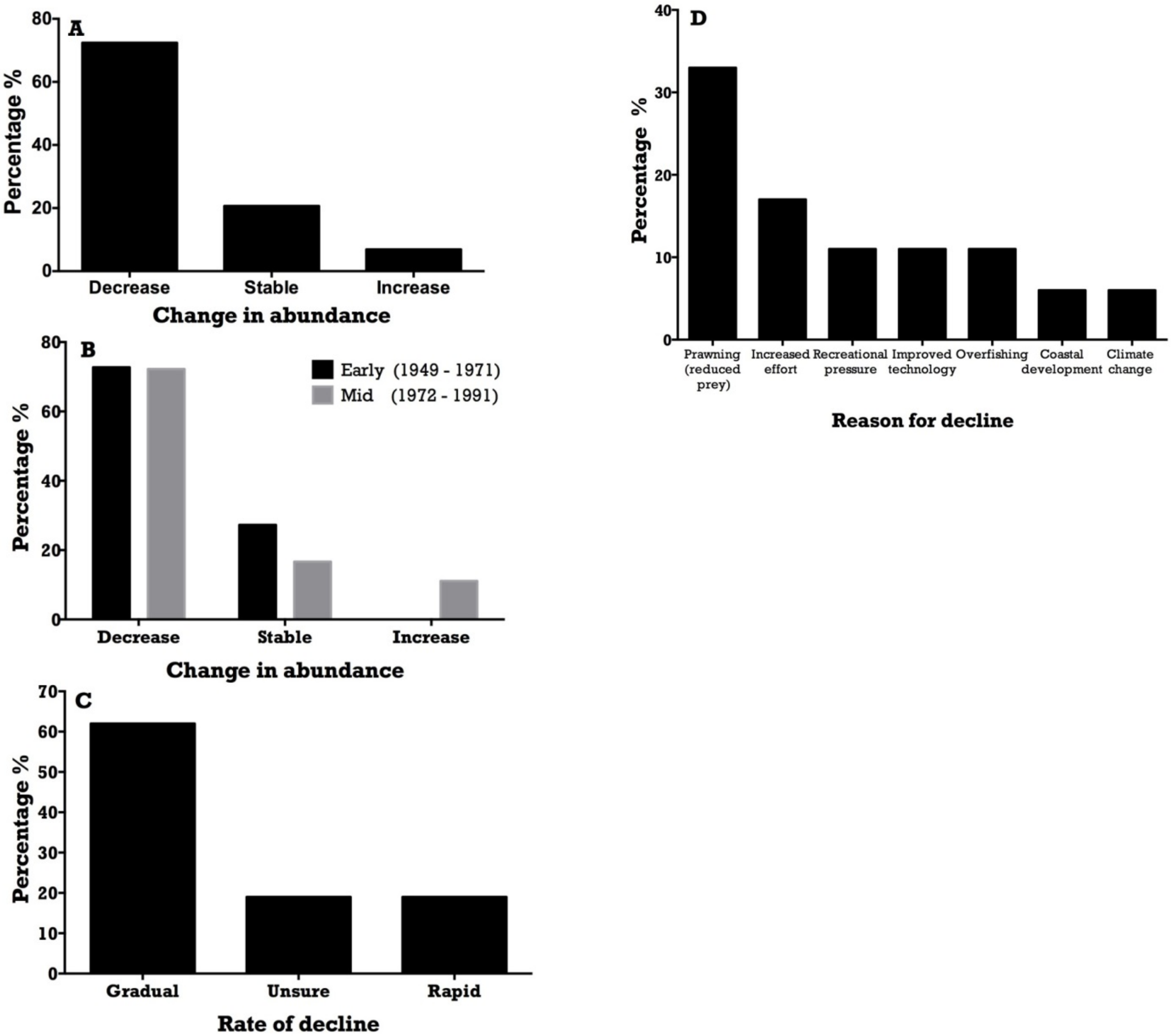
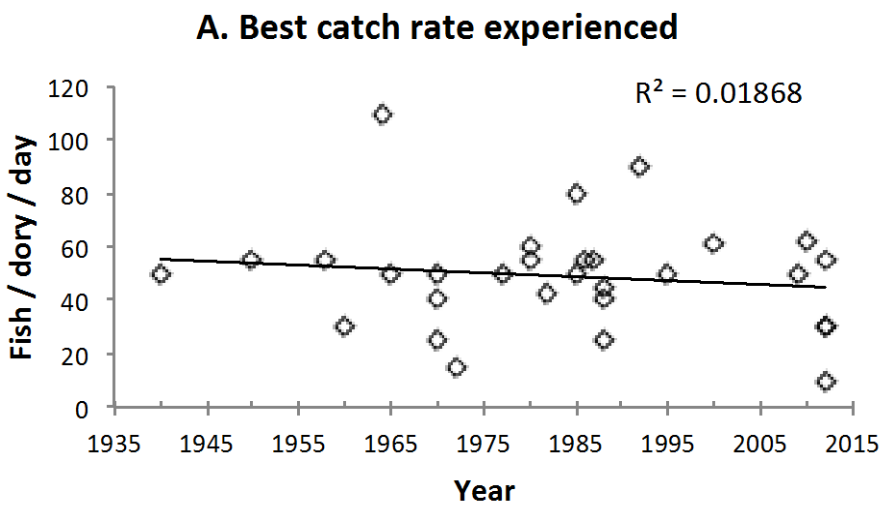


Figure 12 The relationship between (A) best catch rate and (B) duration of best catch rate experienced through time.



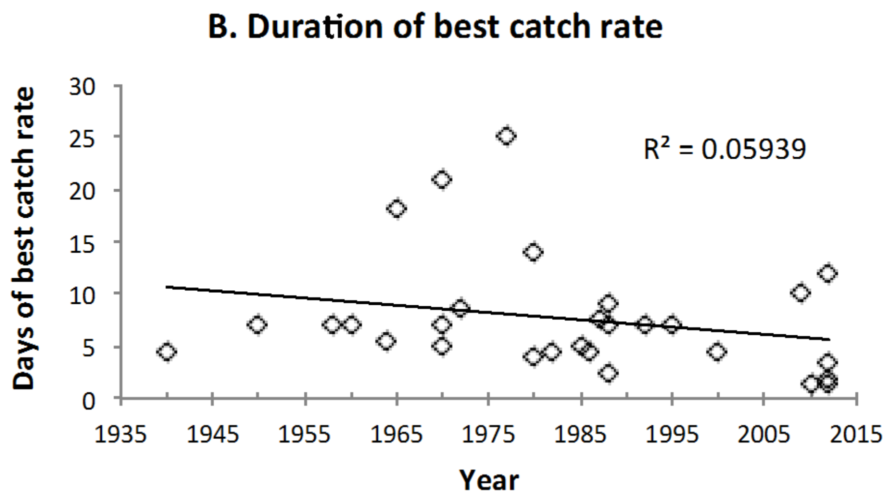
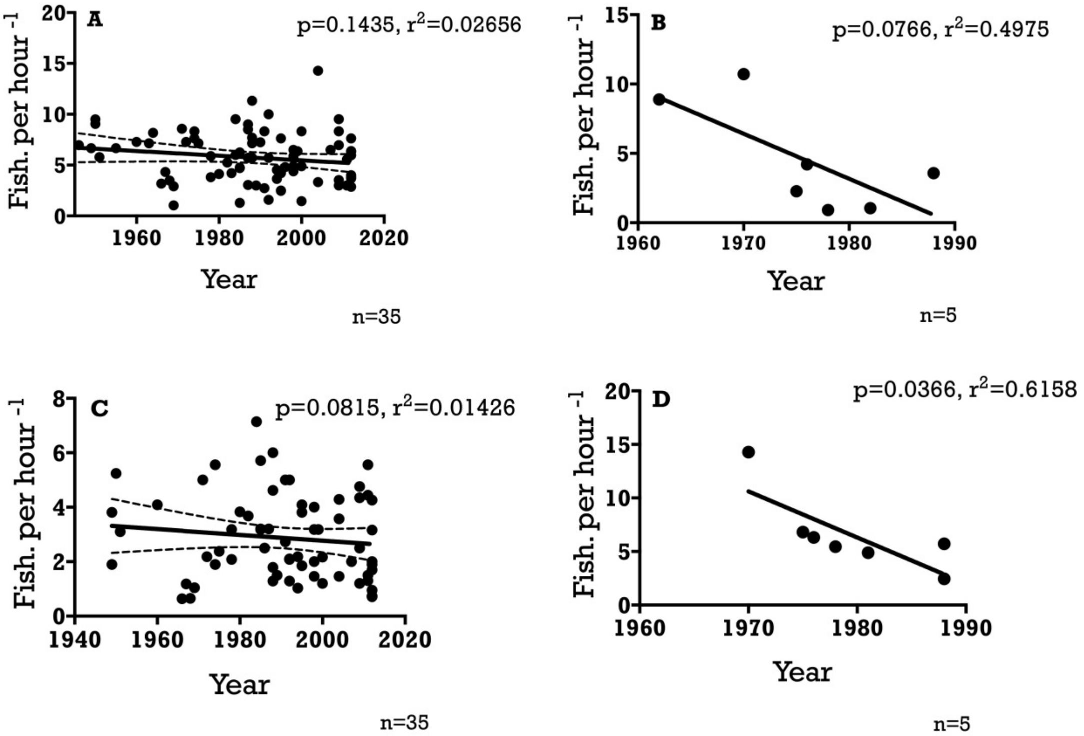


Figure 13 Catch per unit effort reported by individual fishers from two different spawning fisheries (A,C Townsville and B,D Cairns). Fishers reported good (A, B) and average catches (C, D) at the beginning, significant periods and the end/present of their career (Buckley et al., 2012).



Quantifying the benefits of marine protected areas to mackerel aggregating to spawn

Tagging summary

In 2010, a total of 43 Spanish mackerel were tagged with acoustic transmitters with 7 and 37 mackerel tagged on reefs closed and open to fishing respectively (Table 1). Inclement weather hampered the deployment of transmitters and 20 mackerel were tagged in October and 24 tagged in November. Only 22 of the 44 (50%) mackerel were detected within the array and detections were more likely from the mackerel tagged on closed reefs (71% of mackerel detected) as opposed to mackerel tagged on open reefs (46% of mackerel detected).

Similarly in 2011, a total of 62 Spanish mackerel were tagged with acoustic transmitters with 24 and 38 mackerel tagged on reefs closed and open to fishing respectively (Table 1). Tags were deployed earlier in 2011 with 17 in September, 36 in October and 9 in November. Forty-five mackerel (73%) were detected within the array and detections were again more likely from the mackerel tagged on closed reefs (75% of mackerel detected) as opposed to mackerel tagged on open reefs (71% of mackerel detected), although no fish were recorded as removed by fishing.

Presence

In 2010 detected mackerel were monitored by the array for periods ranging from 1 to 98 days (mean = 16.3 days; median = 7 days), though there was considerable variation among individuals in time present within the array (Figure 14A). The zoning status of the reef of capture, tag and release had no significant influence on total days present with mackerel averaging 8.3 and 7.6 days on closed and open reefs respectively ($F_{1,24} = 0.03$; $p = 0.86$). Similarly for consecutive days present zoning status of the reef of capture, tag and release did not have an influence with mackerel spending on average 4.5 and 6.4 days within open and closed reefs respectively ($F_{1,21} = 0.47$; $p = 0.51$)(Figure 15).

In 2011 detected mackerel were monitored by the array from 1 to 152 days (mean = 21.1 days; median = 7 days), and again considerable variation in presence was observed between individuals (Figure 14B). Notably two mackerel were still in the array 152 days post-release equal to the battery life of the transmitters. The zoning status of the reef of capture, tag and release had a significant influence on days present with mackerel averaging 13.8 and 5.3 days within the array when tagged on closed and open reefs respectively ($F_{1,51} = 6.3$; $p = 0.02$). The number of consecutive days present was also significantly influenced by zoning in 2011 with mackerel present for an average of 2.9 and 10.8 consecutive days within open and closed reefs respectively ($F_{1,43} = 11.2$; $p = 0.002$)(Figure 15).

Table 1 A summary of the numbers of mackerel tagged with acoustic transmitters in the two years of the project. Individual reefs and their zoning status (Open – fished; Closed – not fished) are given along with the number of mackerel tagged in at each reef.

Reef	Zoning	Year 2010	Year 2011
Kelso	Closed		3
Helix	Closed		12
Wheeler	Closed	7	10
Rib	Open		1
Lodestone	Open	6	10
Keeper	Open		9
Centipede	Open	8	2
Grub	Open		
Broadhurst	Open		
Pinnacle	Open		
Bramble	Open		
John Brewer	Open	23	15
Davies	Open		
		43	**62**

Figure 14 Abacus plots of Spanish mackerel detected in the (a) 2010 and (b) 2011 spring spawning seasons. The detection data is summarised to the level of reef and day. The transmitter ID identifies individual Spanish mackerel.

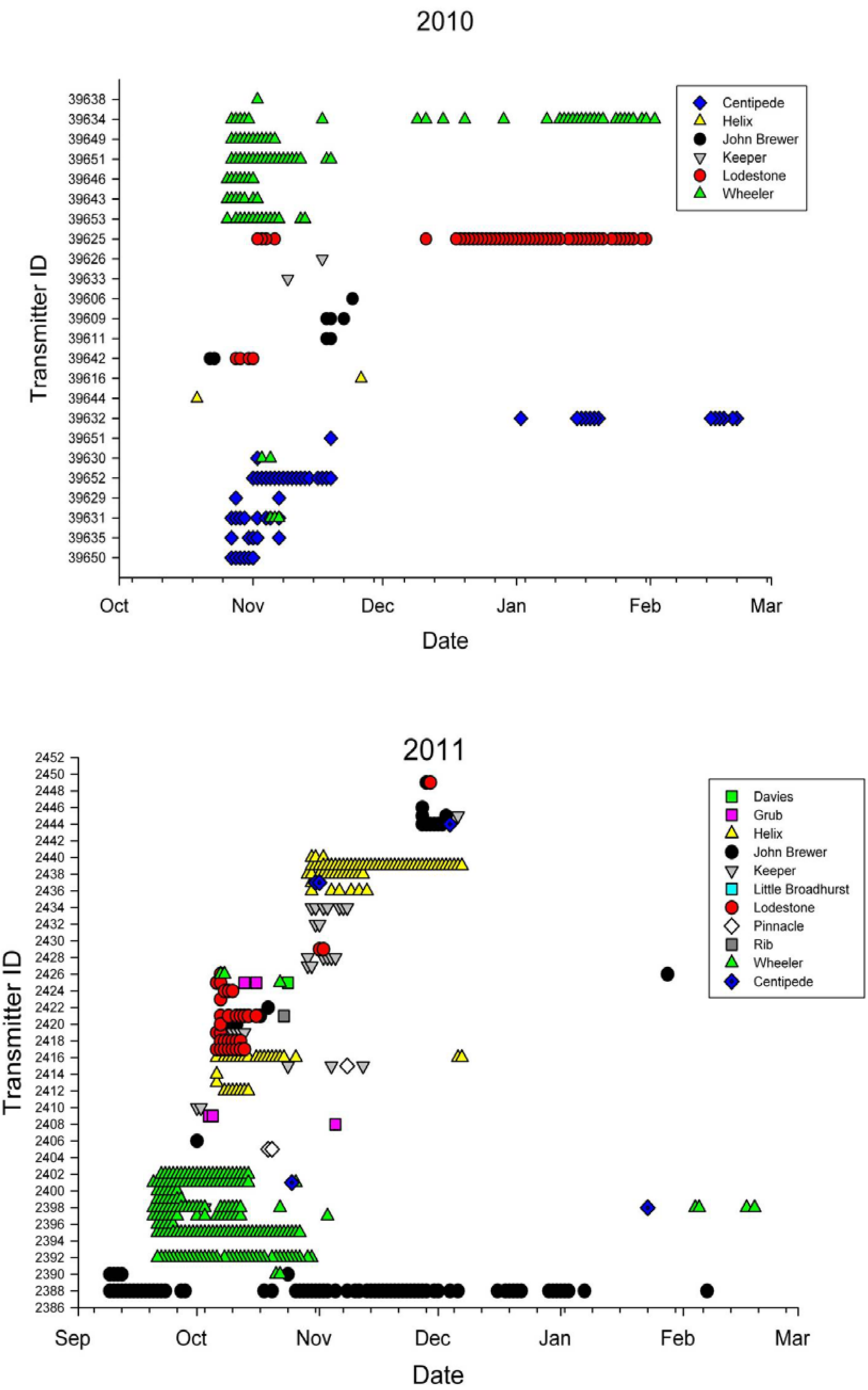
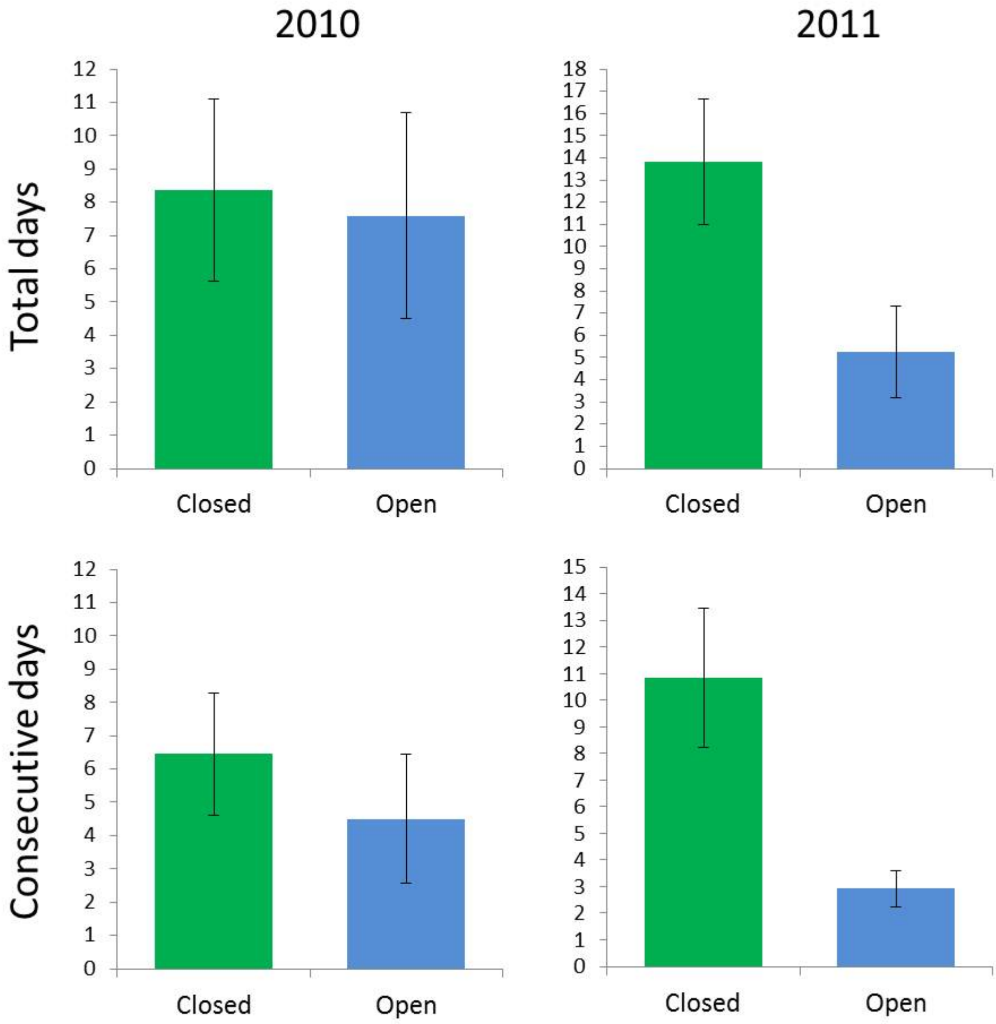


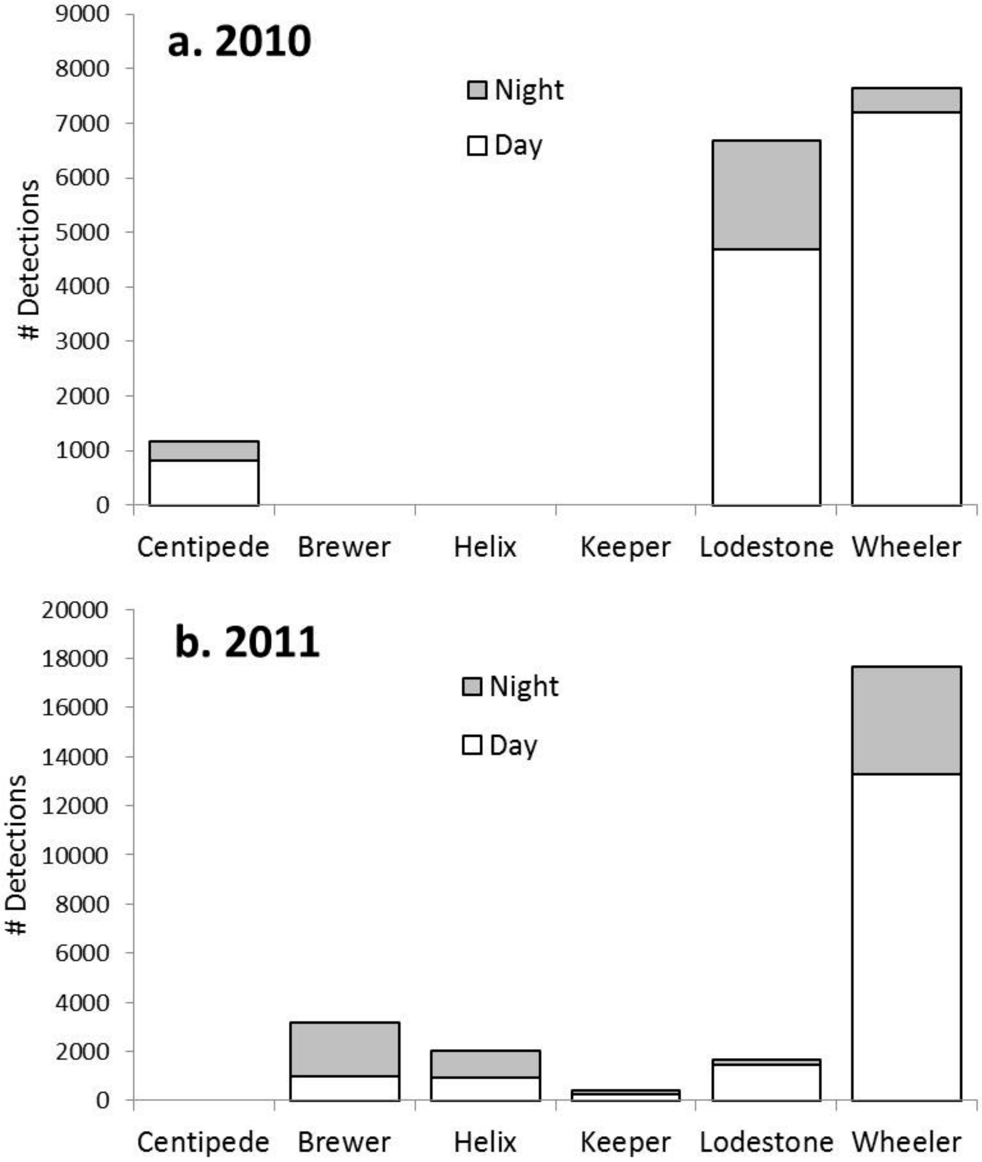
Figure 15 The mean (+/- SE) number of days Spanish mackerel were presence within the array. The effect of zoning status on the total days and consecutive days Spanish mackerel were present on reefs within the array.



Diurnal patterns in presence

In 2010 the receivers at three reefs accumulated more than 500 detections, and for each reef more detections occurred during the day than night (Figure 16A). Chi-square analysis demonstrated that the pattern in day detections was significantly related to the pattern in night detections (Chi-Sq = 1517.1, df = 4, p = 0.000). In 2011 the receivers at five reefs accumulated more than 500 detections, and a clear pattern among reefs was less distinct. Detections were more likely to occur during the day at Wheeler, Lodestone and Keeper Reefs; though at Brewer and Helix Reefs detections were more common during the night (Figure 16B). However chi-square again demonstrated a significant relationship among day detections and night detections (Chi-Sq = 3181.1, df = 4, p = 0.000).

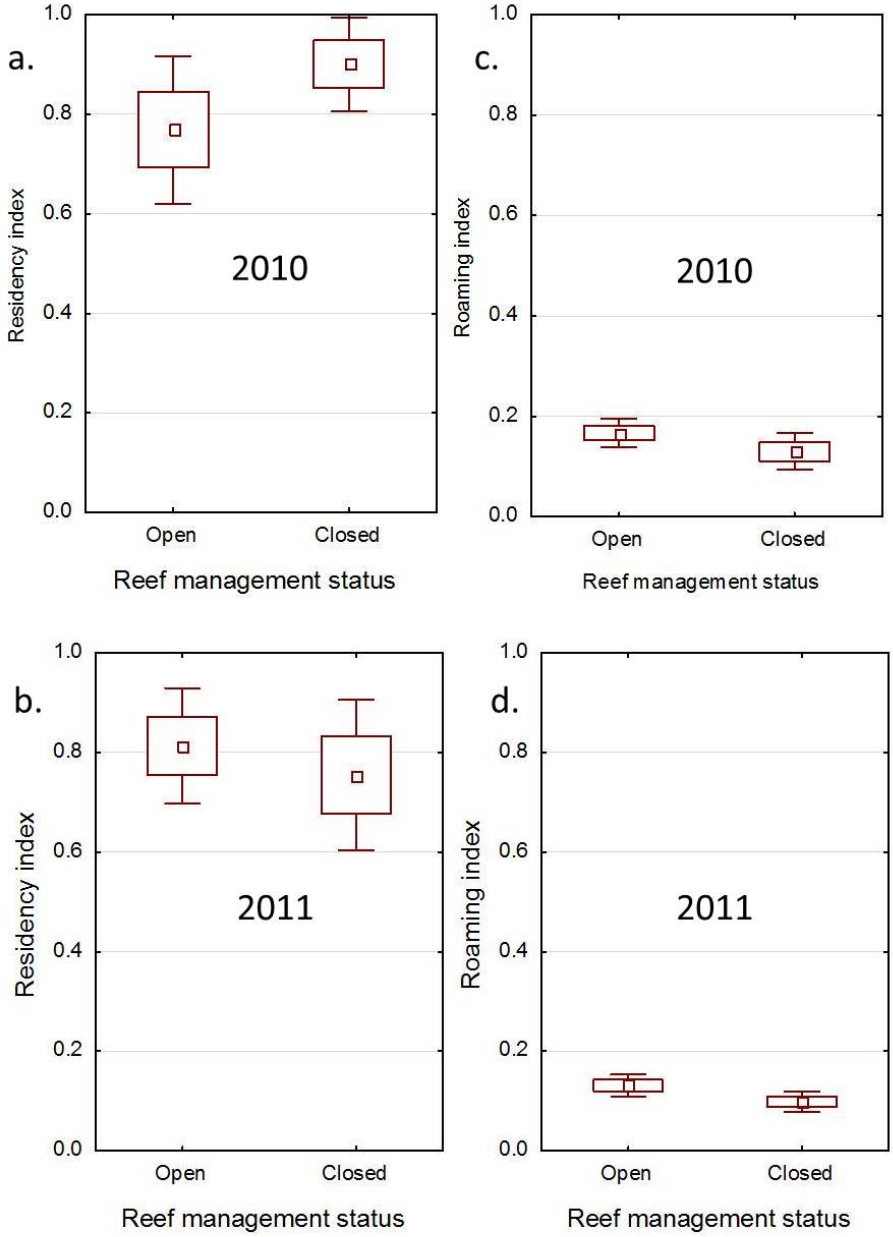
Figure 16 Diurnal patterns in reef presence. For both 2010 (a) and 2011 (b) and for those reefs where at least 500 detections were recorded, the effect of day and night is plotted.



Residency and roaming indices

Residency within the array was consistently high among the mackerel monitored and uninfluenced by management status in both 2010 (Figure 17A; $t_{df,\ 20} = 1.02$, $p = 0.31$) and 2011 (Figure 17B; $t_{df,\ 43} = 0.61$, $p = 0.55$). Conversely, roaming within the array was consistently low among all mackerel though again was uninfluenced by management status in both 2010 (Figure 17C; $t_{df,\ 20} = 1.42$, $p = 0.17$) and 2011 (Figure 17D; $t_{df,\ 43} = 1.99$, $p = 0.053$).

Figure 17 Residency and roaming indices compared among management status for both a. 2010 and b. 2011. Both indices are calculated for the entire array.



Residency Roaming

Interestingly when "reef" residency was calculated rather than array residency, management status had a significant influence with residency higher on closed reefs than open reefs in both 2010 (Figure 18A; $t_{df, 20} = 2.03$, $p = 0.04$) and 2011 (Figure 18B; $t_{df, 43} = 3.12$, $p = 0.003$).

Reef aspect preferences

For all four reefs where aspect preference could be tested, mackerel showed a significant preference. The preferred aspect was variable among the reefs as too was the dominance (Figure 19). At John Brewer, Wheeler and Helix Reefs the northern aspects were most dominated by mackerel detections, while at Lodestone Reef the western aspect was most dominated by mackerel detections. The dominance of a particular reef aspect was most obvious at John Brewer (88%), followed by Wheeler (78%) and Lodestone (77%) Reefs, with Helix Reef (34%) showing the least pronounced preference for a particular aspect of the reef.

Figure 18 Reef residency indices compared among management status for both 2010 and 2011. These indices were calculated to estimate residency tendencies of mackerel for the reef where they were tagged.

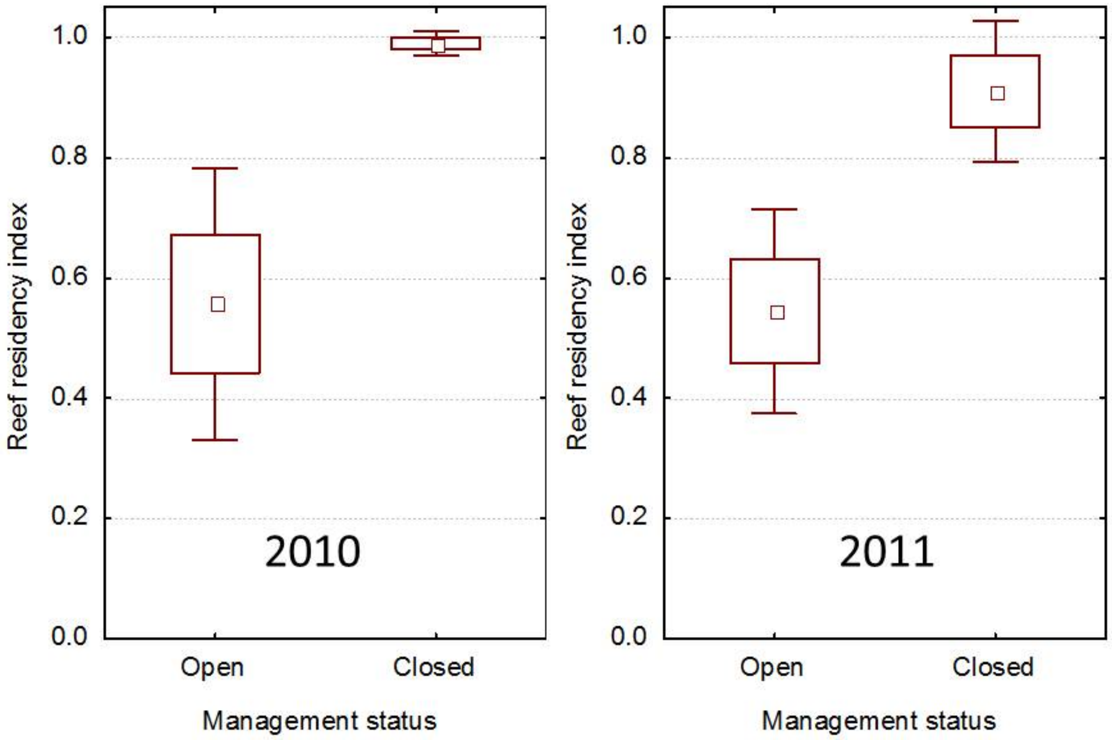
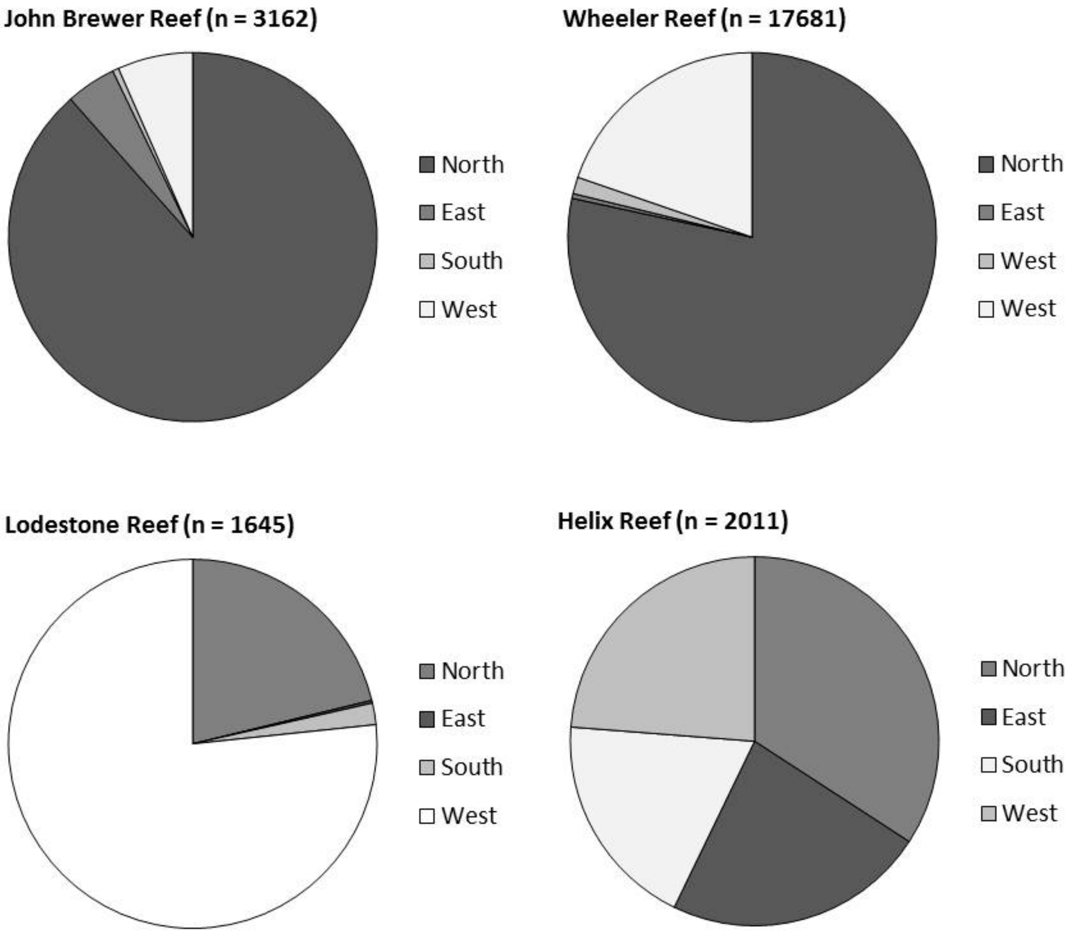


Figure 19 Reef aspect preferences. In 2011, four receivers were deployed around each of four reefs so that each compass direction (north, east, south, west) was represented. These individual reef arrays allowed reef aspect preference to be examined. Samples sizes given are for the total number of detections at each reef.



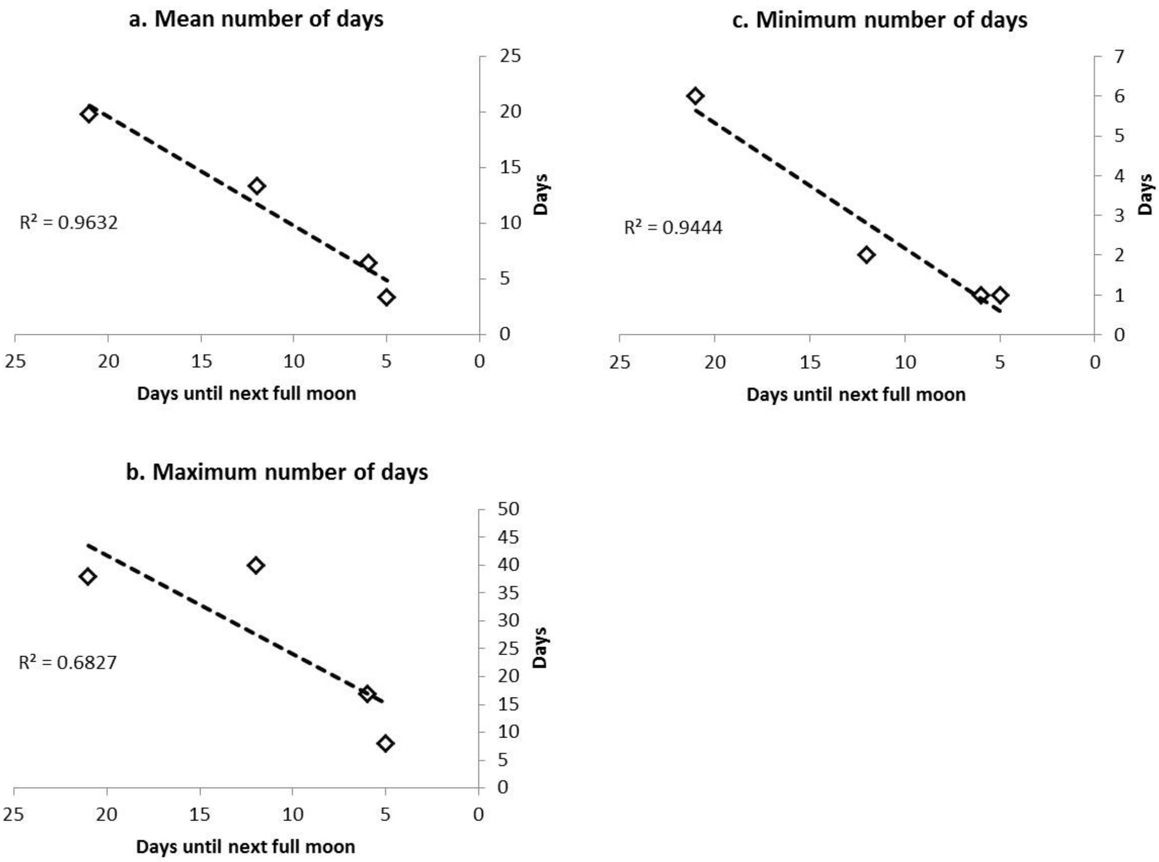
Aggregation persistence

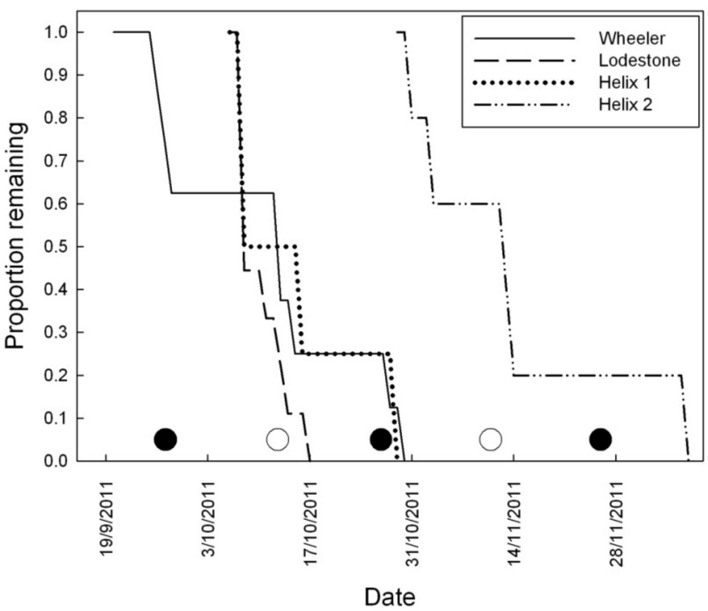
In 2011 enough mackerel were tagged from 4 separate aggregations at three reefs to demonstrate persistence behaviours of aggregations correlated with moon phase (Table 2). Both the minimum and mean number of days individual mackerel persisted within aggregations at a reef was significantly predicted by the number of days prior to the full moon (Table 2)(Figure 20a). Although the maximum number of days a mackerel persisted within an aggregation was not predicted by the number of days until the next full moon, the relationship was positive (Table 2)(Figure 20a). Kaplan Meier plots further demonstrated the correlation between aggregation persistence and lunar phase (Figure 20b)

Table 2 The persistence of aggregations varied among reefs with minimum, maximum and mean days present metrics all varying among reefs.

REEF	# Fish	Min # days	Max # days	Mean # days
Wheeler Sep 2011	8	6	38	19.8
Lodestone Oct 2011	9	1	8	3.4
Helix Oct 2011	4	1	17	6.5
Helix Nov 2011	5	2	40	13.4
		$F_{1,2}$ = 34.0	$F_{1,2}$ = 4.3	**$F_{1,2}$ = 52.3**
		p = 0.03	p = 0.17	**p = 0.02**

Figure 20 The relationship between aggregation persistence and moon phase was explored by A. regression analysis exploring the predictive ability of number of days prior to full moon on minimum, maximum and mean days of aggregation persistence, and B Kaplan Meier plots of the persistence of aggregations .





B

Movement and time spent within the array

A total of 12 between reef movements were detected in 2010 (Figure 22); seven fish made single moves, one fish moved twice and one fish moved three times. For all fish detected in 2010 (n = 22), the time spent on the reefs where tagged was significantly greater than time spent on away reefs (t = 1.74; df = 21; p = 0.04)(Figure 21A). However when only those fish that moved were considered as a subset, time spent on tagged and away reefs was not significantly different (t = 0.36; df = 8; p = 0.36)(Figure 21A).

A total of 27 movements between reefs were detected in 2011 (Figure 22); twelve fish made single moves, four fish moved twice, one fish three times and one fish moved four times. For all fish detected in 2010 (n = 45), the time spent on the reefs where tagged was significantly greater than time spent on away reefs (t = 3.13; df = 44; p = 0.001)(Figure 21B). However when only those fish that moved were considered as a subset, time spent on tagged and away reefs was not significantly different (t = 0.16; df = 17; p = 0.43)(Figure 21B).

Fisher's Exact test revealed that the likelihood of mackerel moving among reefs of different management status was unaffected by reef management status of the reef where tagged in both 2010 (Table 3 Chi-Sq = 1.71, p = 0.19) and 2011 (Table 3 Chi-Sq = 2.94, p = 0.09).

Table 3 Fisher's Exact tests demonstrate that the likelihood of Spanish mackerel moving among reefs in the array was independent of management status.

		Moved to	
	2010	Closed	Open
Tagged	Closed	**0**	2
	Open	5	**5**

		Moved to	
	2011	Closed	Open
Tagged	Closed	**0**	7
	Open	7	**13**

Figure 21 Time spent on tagged reef (home) versus time spent other reefs (away) for both 2010 (a) and 2011 (b).

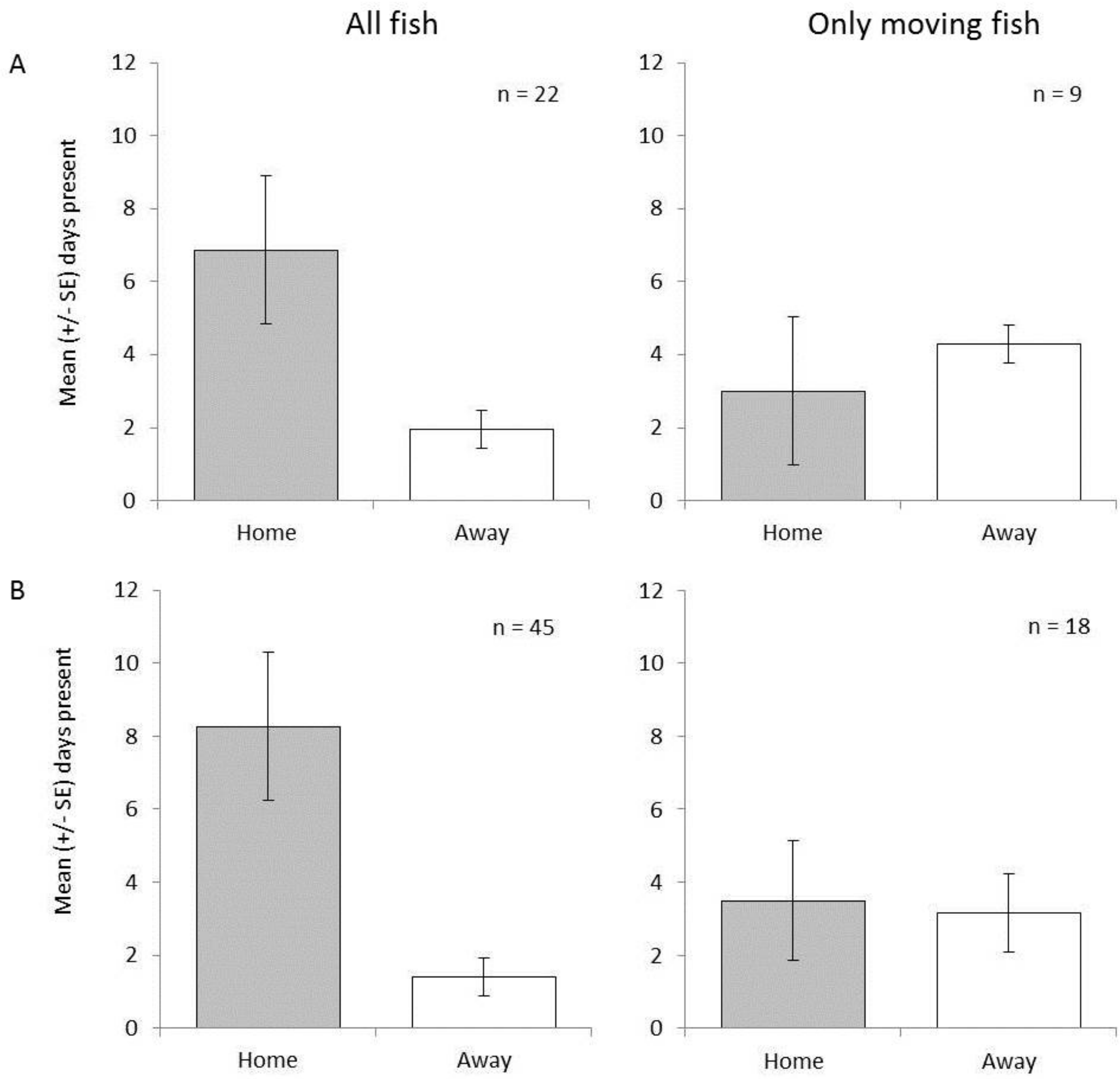
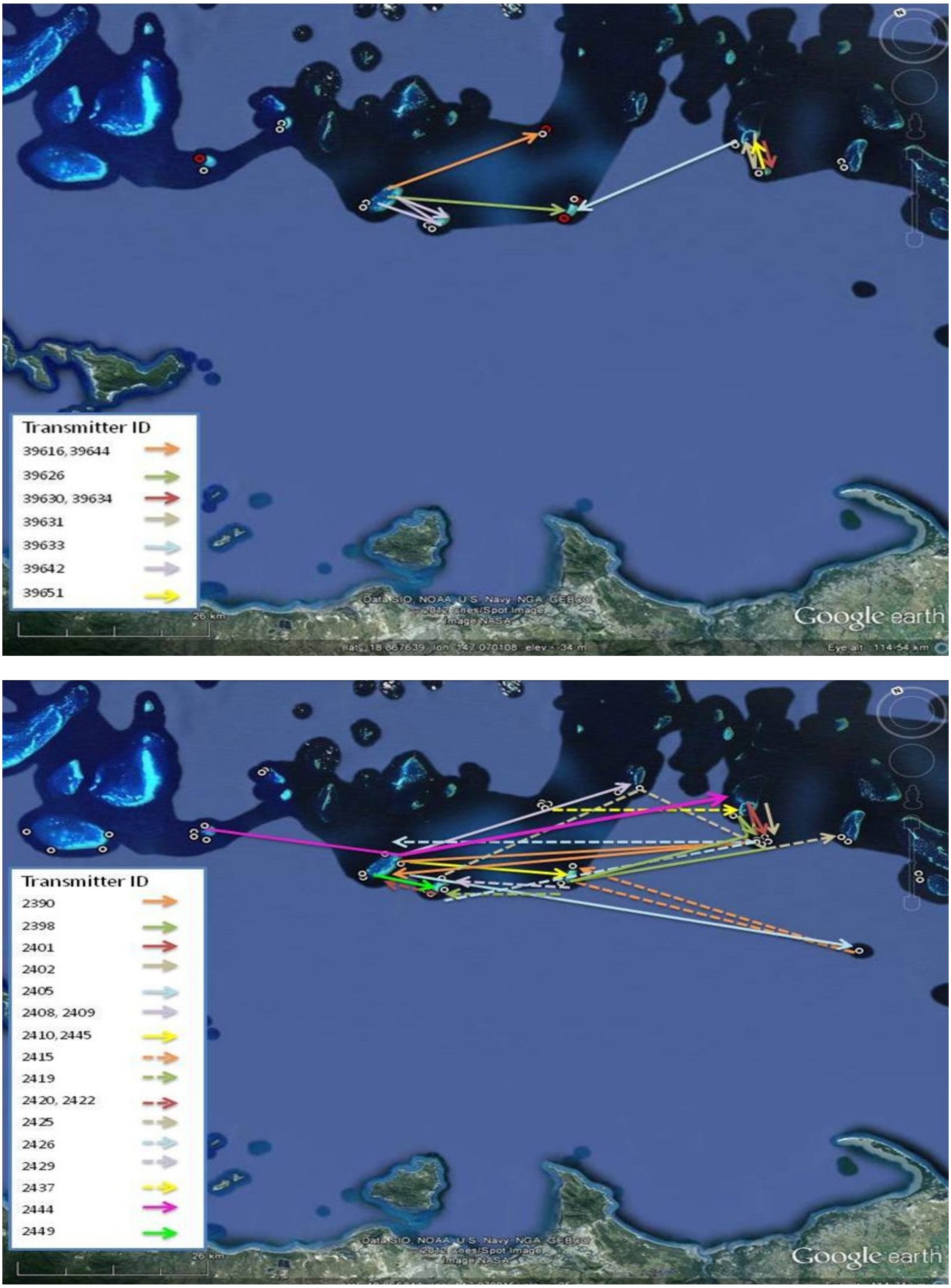


Figure 22 Movements detected among reefs within the acoustic array. In 2010 (top) 12 movements among reefs were detected by 9 fish, while in 2011 (bottom) 27 movements among reefs were detected by 18 fish.



Management strategy evaluation of the benefits of spatial and/or temporal closures

The effect of 5 or 9 day closure on catch was minimal in most regions with Townsville being the clear anomaly (Figure 23). A 5 day closure would impact less than 5% of the annual catch in all regions excepting Townsville where 10% of catch (post-2004) would be prevented. Impacts were more pronounced for the 9 day closure with post-2004 impacts at Townsville around 20% of annual catch. Again post-2004 impacts at other regions were consistently less than 5%. Workshop participants agreed that dependent on future scenarios for the fishery these reductions in catch may not be enough.

The outcomes of the acoustic monitoring suggest lunar month durations of aggregations of Spanish mackerel. On this basis, post-workshop discussion has suggested modelling the impacts of month long closures on annual catches. We modelled the impact of a lunar closure within a. October, b. November, and c. October and November. An October or November closure would impact around 30% of the annual catch taken from latitude 18, while impacting less than 10% of annual catch taken north or south (figure 24). A closure that encompassed both October and November would reduce annual catch within latitude 18 by more than 60%, while northern catches would be reduced by around 15% and southern regions less than 10% (Figure 24).

Figure 23 The effect of 5 or 9 day closures on the proportion of annual Spanish mackerel taken by region for the Queensland east coast fishery. The impact of these closures was modelled as both have been used for temporal management of the co-occurring reef line fishery. Models were run with the complete CFISH data series. The model also incorporated two times – pre-2004 (dashed line) and post-2004 (solid line).

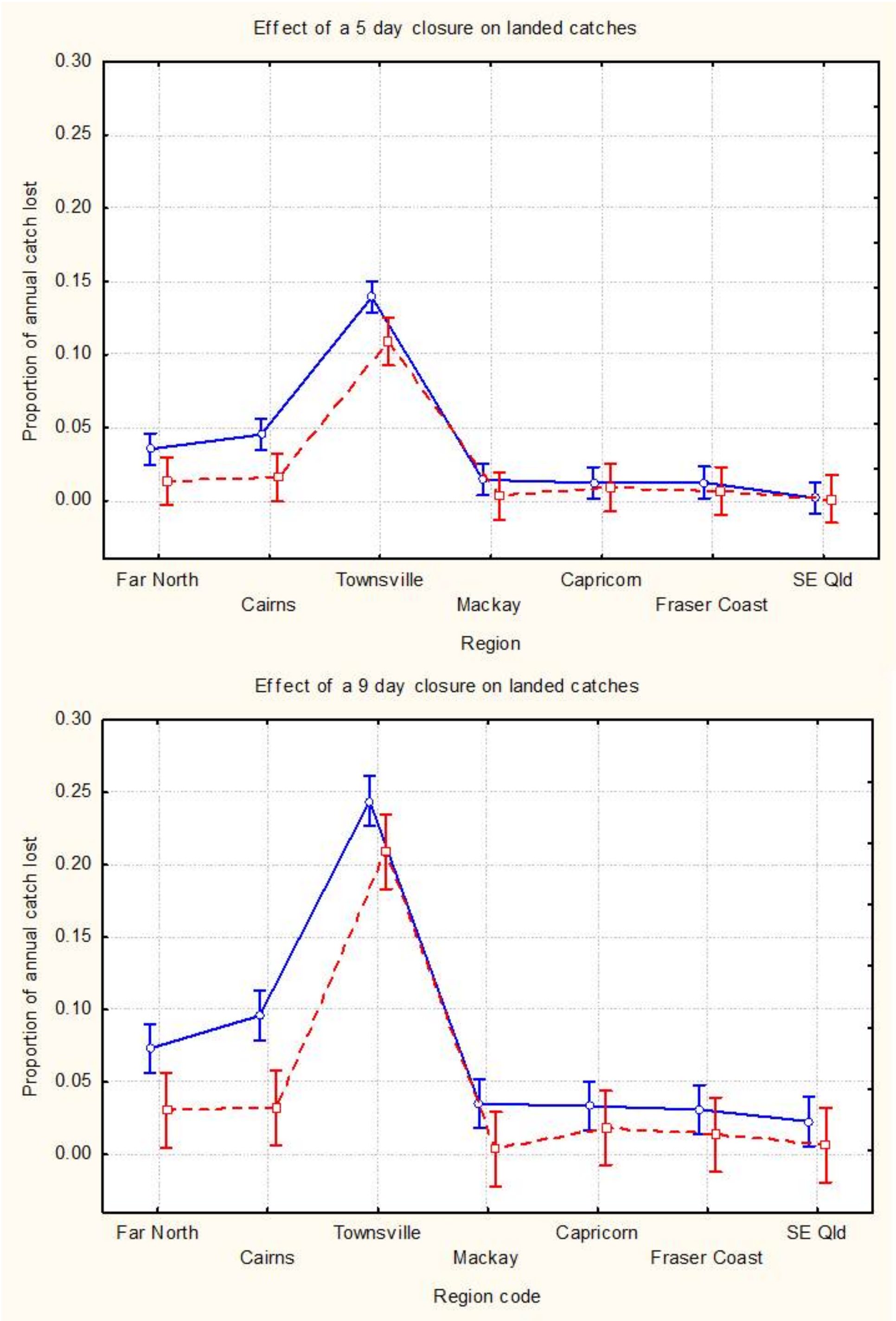
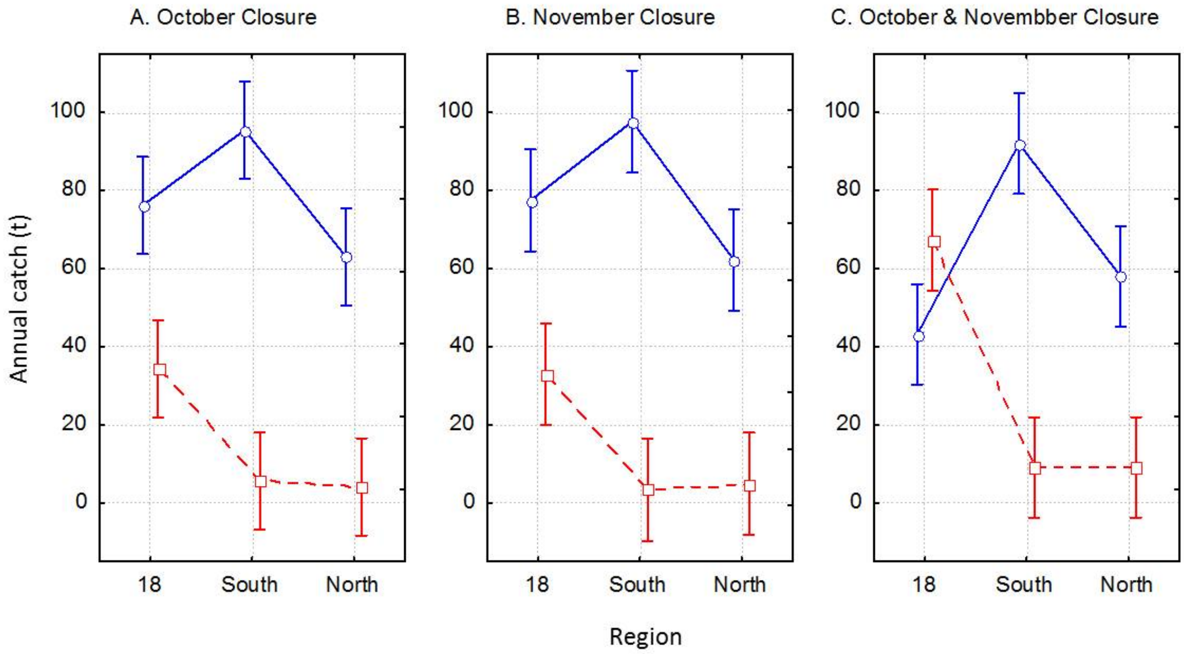


Figure 24 The impact of temporal closures on annual catch modelled across three regions using contemporary catch data (2005 to 2011 inclusive). The catch impacted is highlighted by the dash line, while the nonimpacted catch is highlighted by the solid line.



Discussion

Documenting the temporal and spatial trends of the spawning aggregation fishery

Contemporary logbook data (1988-current day) clearly demonstrates significant decreases in effort and catch have occurred in the Queensland east coast Spanish mackerel fishery. Most notable is the steep decline in both catch and effort that occurred in 2004 coinciding with the introduction of a Total Allowable Commercial Catch (TACC) by QDAFF and spatial protection of the Great Barrier Reef was reviewed by the GBRMPA to increase reef protection from 16.7 to 32% of reef perimeter (McCook et al., 2010). Despite anecdote suggesting many fishers departed the fishery because of perceived over-regulation related to these two management changes that occurred in 2004, Holmes (2008) also notes other factors including fishers operating in higher value fisheries (live coral trout), weather, rising fuel prices, difficulty in employing and maintaining reliable crew, and increased competition from imports also affected participation. Regardless of this large perturbation in the logbook data, clear signals are present that the historically important spawning aggregation fishery within latitude 18 has diminished in contemporary times. Not only has the proportion of state-wide annual catch taken from latitude 18 declined, within latitude 18 the proportion of annual catches taken from spawning months as compared with non-spawning months has also declined. These trends are also present in the number of active licences participating in the spawning aggregation fishery.

In contrast to the declining trends in contemporary annual catches taken from the historically important latitude 18, the proportion of annual catches taken from more southern regions (latitude 19 to 26 inclusive) has increased significantly. Interestingly these catch trends persist even though the number of licences accessing the Spanish mackerel fishery in the region has significantly declined. The increase in catch in this region may be reflective of the premium prices offered for whole-on-ice fish given the close proximity of these fishers to the southeast Queensland markets as well as the accessibility of fishing grounds (Tobin & Mapleston, 2003). The decrease in participation may be related to the introduction of TACC and a latent effort policy introduce by Fisheries Queensland that removed many low activity line licences in 2006. Overall however, the patterns of participation in the south-eastern Queensland fishery suggest that market forces may encourage participation in a whole-fish fishery the returns a price premium when compared with the frozen fillet product that dominates the spawning aggregation fishery.

It is important to acknowledge the limitations of the contemporary CFISH data. Although for some Queensland fisheries, calculating a robust catch-per-unit-effort (CPUE) metric from the CFISH data is possible (eg Tobin et al., 2010), the Queensland east coast Spanish mackerel fishery data is compromised. Targeting behaviour and fishing effort are variable both within and among licences, and these vagaries are not captured by the logbook data. To robustly track CPUE trends and relate trends to fishery performance requires knowledge of targeted catch and non-targeted catch. Targeting behaviour is not recorded to an appropriate level such that a hypothetical daily catch of 52 kilograms of Spanish mackerel may have been taken as an incidental by-product catch by a vessel targeting coral trout rather than by a dedicated Spanish mackerel vessel that actually spent the day targeting Spanish mackerel. Similarly, fishing effort may vary among fishers (licences) with one Spanish mackerel fisher operating from a single “main boat” while a co-occurring fisher may operate a “main boat” with two accompanying and crewed dories. Accordingly, the description of trends in the east coast Spanish mackerel fishery incorporated in this chapter does not include calculating CPUE and describing trends therein. The trends in fishery performance relate only to annual catch and annual effort.

A further limitation of the CFISH data is the relatively broad spatial resolution (30 X 30 nautical mile grids) of data recorded by commercial fishers. While data is recoded at this broad level monitoring reef specific catch and effort trends is not possible. When the acoustics monitoring component of this project clearly demonstrates a high degree of reef fidelity by aggregations of Spanish mackerel, reef specific effort and catch information would immeasurably improve the ability of all stakeholders to monitor and assess the status of annual spawning activity, aggregations and fishery sustainability. As Tobin et al (2010) were able to demonstrate for coral trout, the CFISH data series can be a powerful resource for tracking the productivity and sustainability of Queensland Fisheries. We consider a combined effort by both commercial fishers and QDAFF could improve the quality of information recorded for the Queensland east coast Spanish mackerel fishery that would ultimately benefit all stakeholders. As recent research has demonstrated Spanish mackerel is particularly vulnerable to fishing during their annual spawning season (Tobin et al 2013), improved data collection should be considered mandatory.

In the absence of compulsory logbook data prior to the introduction of CFISH logbooks (1988), fisher knowledge (oral histories and personal logs) represents a valuable source of information that we used to reconstruct historical changes in the ECSMF from 1949 to 1988. The project provided compelling evidence confirming the popular anecdote that the Spanish mackerel spawning aggregations have contracted in both spatial and temporal scales. A general consensus among the inter-generational fishers is that a decline has been observed in the Townsville spawning aggregation, even though the catch rate may appear stable over time (note here, the previous discussion of limitations on calculating a robust CPUE for the ECSMF). According to fishermen interviewed the apparent stable catch rate may be explained by a decrease in total effort (number of active fishers and days fished) accompanied by an increase in effort (gear and technological creep). Equally parsimonious is the likelihood that the strong aggregating characteristics of Spanish mackerel manifest in hyper-stable catch characteristics.

The most significant outcome of the historical reconstruction of the spawning aggregation fishery is the first time documentation and quantification of the commercial extinction of a spawning aggregation fishery that previously existed on reefs east and south-east of Cairns. Popular anecdote among long-term commercial fishers as well as respected Scombrid researchers has suggested a historically important spawning aggregation fishery centred on reefs east and south-east of Cairns became commercially extinct in the mid-1990s. This project has quantified the decline and extinction of this sub-sector of the ECSMF. The Cairns fishery that flourished through the 1960-80s period (McPherson 2007) has not been commercially viable for at least the last two decades. Interestingly, McPherson (2007) also suggests the commercial extinction of a Lizard Island based spawning aggregation fishery as well. Unfortunately, this project was unable to interview any fishers with either direct experience or second-hand information about the Lizard Island fishery, so no further commentary is applicable here. This anecdote does however add significant support to the global picture of the status of the ECSMF: that of a fishery in decline, and a fishery that has suffered some level of serial depletion as a result of continued commercial fishing.

As this outcome demonstrates, fisher knowledge can provide important information on trends in fishery performance when no formal recording or logbook information is available. This is particularly important where a fishery may have a long history of activity, though formal records are only available for a small portion of that history. It is important to acknowledge that the snowball sampling methodology used has some limitations. As a consequence of the snowball sampling only a sample of the commercial operator population were interviewed, thus all parameter estimates and trends have some statistical uncertainty. When using fisher knowledge, one has to account for a range of biases. Fisher perceptions can contain anomalies due to recall bias, memory illusion, individual, generational amnesia and high catch variability, which can exaggerate or mask the perception of the trend (Papworth et al., 2009; Daw 2010). This investigation attempted to account for these biases by a range of methods including sampling a good representation of the active skilled fisher population (33.3%) and a range of generations (mid, old). Also fishers were questioned about a range of catches i.e. best, good, average and poor. The basis for this was to assist fishers to account for variation in their catches.

Quantifying the benefits of marine protected areas to mackerel aggregating to spawn

Marine Protected Areas (MPAs) are increasingly being used to manage fisheries resources, however understanding and accounting for adult movement patterns in their design remains a critical knowledge gap (Sale et al., 2005). Although the GBRMP MPA network exists primarily to protect the unique biodiversity of the World Heritage Area (McCook et al., 2010), the protection of specific fishery exploited species was also considered during design and implementation (GBRMPA, 2005). For example, Kelso Reef from within latitude 18 was included in the increase in spatial protection of the GBR in July 2004 acknowledging zoning the historically important fishing reef a marine national park (no fishing) would confer some protection to Spanish mackerel aggregating during the spawning season (GBRMPA, 2005). However despite these actions and stated objectives no assessment of the success of these closures has been attempted.

The acoustic monitoring of this project has provided significant insight into the aggregating and movement characters of Spanish mackerel during their annual spawning season. This information is timely as concerns have been raised repeatedly about fishing targeting Spanish mackerel spawning aggregations (Russell, 2001; Russell & Pears, 2007), and these concerns have recently been quantitatively validated by Tobin et al (2013) who describe Spanish mackerel as the most vulnerable line caught species to fishing during spawning.

The most significant outcome of the acoustic monitoring component of the project was that the highly mobile Spanish mackerel remains very site attached during the time they are present within the spawning aggregation area. Spanish mackerel display a strong tendency to aggregate at a particular reef and movement among the reefs of the spawning reef complex is rare. These behaviours indicate that while mackerel are present within the spawning reef complex they are tightly associated with a particular reef, and once they leave that reef they tend to leave the spawning reef complex. Movement among reefs was infrequent and when it did occur, the time spent at reefs other than the tagging reef was generally short. These observations suggest the Spanish mackerel move into the spawning reef complex, aggregate on a chosen reef and presumably spawn, then leave the spawning reef complex.

The additional receivers that were deployed in 2011 as an in-kind contribution of the National Environmental Research Program allowed for the definition of fine scale within reef aggregating patterns. On four reefs sufficient receiver coverage was available to determine the mackerel aggregations on each reef had a preferred aspect where most time was spent. There was variability among reefs in the strength of this preference, though consistency for the north-western aspects of these reefs. This result confirms the anecdote from long-term fishers that aggregations can display a distinct preference for a particular reef aspect. We believe the most parsimonious explanation of this behaviour is prevailing currents that consistently impact the north-western aspect of emergent reefs during the spawning season. Luick et al (2007) identified a southeast flowing current season occurs in the GBR lagoon from August to December each year. Current direction has been shown to strongly influence the positioning of coral trout on reefs (Zeller, 2002), with trout preferring the up-current side of structure. We consider it likely this behaviour is mimicked by Spanish mackerel resulting in their predictable presence on a particular reef aspect.

Management status appeared to have an effect on the aggregating characteristics of Spanish mackerel. In 2011, total days and consecutive days spent within the array were significantly more on reefs closed to fishing as compared with reefs open to fishing. Despite some discussion in the spawning aggregation literature about the impacts of fishing and associated vessel traffic on aggregations (Heyman & Kjerfve, 2007), there is no yet any empirical evidence that aggregative behaviours change with the presence of fishing or vessel traffic. It is possible the longer time periods Spanish mackerel persist on no fishing reefs is linked to the absence of fishing and vessel activity. Some fisher LEK links the extirpation of the Cairns spawning fishery (see Chapter 2) to disruption by fishing and tourist vessel traffic and associated noise. Further research is required to determine whether these actions may occur.

The observation, particularly during 2011, that no mackerel moved from the more southern reefs to reefs in the northern limits of the spawning reef complex was an interesting finding particularly for active commercial fishers. During the 2011 season, fishers reported that Rib and Bramble Reefs “fished better” than all the other spawning reefs. This suggests large and persistent aggregations occurred at both of these reefs during the 2011 spawning season. Interestingly none of the mackerel tagged on reefs (n = 61) to the south moved the relatively short distance north (less than 20kms) to these reefs. This observation further supports the conclusion that aggregations display strong reef fidelity. With the benefit of hindsight, it is evident from these findings that to more completely understand the aggregating characteristics of Spanish mackerel within the spawning reef complex and during their annual spawning season, a sample of mackerel from each reef aggregation needs to be tagged and monitored preferably simultaneously.

Interestingly the behaviours described for Spanish mackerel are not too dissimilar to that recently described for the black jewfish (*Protonibea diacanthus*) in Northern Territory waters where acoustically monitored individuals did not move between aggregation sites (Buxton et al. 2010). Such behaviour, cautioned these authors, could lead to serial depletion and localised extirpation of aggregations. Indeed, severe localised depletion has been recorded for black jewfish on the western coast of Cape York (Phelan 2002). The fact that extirpations of aggregations of Spanish mackerel also appear to have occurred near Cairns, further highlights the vulnerable behaviours of Spanish mackerel and the need for management to explicitly consider these.

Quite rightly MPAs are considered an important option in the tool box of fisheries management (Buxton et al., 2010), with the number of empirical examples of their ability to protect and/or rebuild exploited fisheries growing (Russ et al, 2008; Knip et al, 2012). Given the current fully fished status of the Queensland east coast Spanish mackerel fishery combined with the existing desire for increased access by multiple fishing sectors, further definition of the potential benefits of spatial protection, both within and outside of the spawning reef complex, for the sustainability of this fishery is paramount.

Conduct a MSE to quantify the benefits of spatial and/or temporal closures

Clearly, the impact of a temporal closure could be immense. The historical reliance of many fishers on the spawning aggregation fishery likely complicates the introduction of such a closure as the social and economic impacts are likely to be very high. The introduction of temporal spawning closures for the co-occurring Coral Reef Fin Fish Fishery (CRFFF) created social and economic hardship (Tobin et al 2009) that resulted in a consultative review and ultimately fewer closure days (Walshe & Slade, 2009). This example clearly demonstrates caution needs to be applied when considering temporal closures for fisheries resources as the cost of the closures can be significant.

The introduction of temporal closures for the CRFFF is also a good example of a management measure being introduced without sufficient initial consultation, no clear objective of what the closures were to achieve, no monitoring of potential benefits and no assessment of impacts on fishers (social, economic or other) nor of the costs of enforcing the closures.

Importantly though, should Spanish mackerel remain at the fully fished status or worse increased catch push the fishery into overfished status, spatial and temporal closures would clearly aid in fishery recovery. In achieving the correct adaptive management measures we would encourage a wide consultative approach that also seriously considered a co-management approach. Given the spawning fishery is predominantly a fishery for commercial fishers, the number of participants is low and the area of the fishery is confined such characters suggest successful co-management is more likely (McPhee 2009). For example, some fishers suggest a system of rotational closures may be better received by industry as long as the closures are truly an exercise in co-management. Certainly the impacts of such closures on the economic viability of individual fishers and businesses would need close scrutiny. In addition, the need for similar spatial and/or temporal closures for the south-eastern Queensland fishery should be considered as this region supports the significant effort and catch by the ever growing recreational sector.

Conclusion

This project provides the foundation for improved management of the Queensland east coast Spanish mackerel fishery. Firstly the reconstruction of the historical trends of the fishery clearly identifies the extent of the spatial and temporal contraction of fishery activity throughout the history of spawning aggregation targeted fishery. The commercial extinction of at least one spawning aggregation has been quantified, and suggests serial depletion of aggregations may be possible. Secondly, the novel acoustic monitoring technology defined an aggregating behaviour that included very high reef residency and low rates of movement among reefs further exemplifying the vulnerability of Spanish mackerel to fishing. Finally, modelling the impacts of temporal closures on fishery productivity clearly identified closures targeting the spawning aggregation fishery (that occurs in the months of October and November) would substantially reduce annual harvest levels of at least the commercial sector.

The conundrum faced by stakeholders with interest in the ECSMF is that while clearly historical commercial effort and catch has likely contributed to stock declines and extinction of some aggregations, the contemporary pressure on the ECSMF is largely from the recreational sector. This means that management goals seeking to cap or reduce annual harvest levels from the ECSMF may be better focused on the recreational rather than commercial sector. However such a management approach will remain difficult until better more robust information and data is available to describe the spatial and temporal trends in recreational effort and catch.

Data collection and quality needs to improve so that future management of the ECSMF is effective. For the commercial sector that targets the spawning aggregation fishery, recording reef specific effort and catch would immeasurably improve the understanding of trends in aggregation persistence (size and duration). While serial depletion of aggregations is a likely consequence of fishing spawning aggregations of the ECSMF, collecting data that better reflects the units of space in which aggregations occur (individual reefs) will help tracking changes that may occur in stock status. For the recreational sector, improved data on when and where peak catches occur would also immeasurably help future management. While bag limits remain an ineffective management tool for controlling total harvest (Cox et al 2002), future management of harvest from the recreational sector may need to rely on temporal or spatial closures that limit access to the ECSMF at times and/or locations where large catches occur. While Tobin and Mapleston (2004) described broad scale temporal and spatial trends in recreational harvests, future effective management will require much finer scale information. Currently, very little is known about the temporal and spatial patterns of recreational catch.

Finally, an important mandatory next-step following on from this project is the need to address the allocation of the annual harvest of Spanish mackerel among the competing commercial and recreational fishing sectors. This action will be of increased significance if future assessments of the status of the resource determine catch reduction is necessary. For the commercial sector this is particularly important due to the property right and economic value attached to the individual transferable quota system managing fishers activities. For recreational fishers, no fisher is likely to agree to an increasing activity in the ECSMF that will ultimately push the fishery into an overfished status. A catch sharing arrangement should be discussed as a matter of course.

Implications

Assessment of the impact of the outcomes on end users such as management, industry, consumers, etc in Australia (where possible provide a statement of costs and benefits).

The major implication of this research, the demonstration that Spanish mackerel are vulnerable to fishing and the serial depletion of some historically important spawning aggregations has occurred.

The ECSMF has been under increasing scrutiny in over recent years with four individual assessments (O'Neill & McPherson, 2001; Hoyle 2002; Welch et al 2002; Campbell et al 2012), all of which have suggested a risk of overfishing. The status of ECSMF is scrutinised due to the sustainability goals of the requirements of the QDAFF (Queensland Fisheries Act), as well as the conservation goals of Commonwealth agencies the GBRMPA and the DoE (EPBC Act). The outputs of the research will help sustainability goals of QDAFF in providing clear and defined information about the aggregating characteristics of Spanish mackerel while they are most vulnerable to fishing; pivotal information for introducing effective temporal spawning closures should such a management action be required. In addition, the definition of aggregating characteristics also addresses information requests from the GBRMPA (Russell, 2001; Russell and Pears 2007) and the DoE (http://www.dpi.qld.gov.au/documents/Fisheries_SustainableFishing/EastCoast-SpanishMackerel-RecsAndConds-2009.pdf).

While the project has demonstrated that protection of aggregations of spawning Spanish mackerel is likely to be very effective with either spatial closures of select aggregation reefs or temporal closures during periods of high catches, the implications of either strategy are difficult to gauge in the absence of a stated management goal by the QDAFF. The implications for the commercial sector are likely to be negative in the short-term, though through a co-management arrangement whereby reef closures may be negotiated and rotated through years mid- to long-term benefits may accrue through more sustainable fishing and possibly a rebuilding of aggregations.

The implications for recreational fishers are more difficult to ascertain again. While the sectors participation in the ECSMF continues to grow, a management action in the short-term is mandatory. At the very least more extensive and robust monitoring is needed. Secondarily, a better suite of management tools may be required to control the total harvest made by this sector each year.

Recommendations

The primary recommendation is to better define the recreational harvest so that the overall catch from the ECSMF can be determined with greater certainty than is currently available. Definition of the recreational harvest will allow the stock assessment to be completed with greater certainty than is currently available (range of possible harvest levels 702 – 1467t annually). The current and conservative estimate of annual catch taken by all sectors of the ECSMF is 700-800t. Should this catch increase, a management response to reduce catch would be imperative.

In addition, the project would recommend that primary sites of recreational fishing effort and catch be identified. As Spanish mackerel is a obligate and transient aggregating species (Tobin et al 2013), it is likely that other locations along the Queensland east coast seasonally support large aggregations of Spanish mackerel that are opportunistically targeted by recreational fishers. Should these out-of-spawning-season aggregations have similar characteristics as the spawning aggregations as identified by this project, spatial and/or temporal management tolls may be applicable for controlling or limiting the currently burgeoning recreational harvest.

Most importantly, attention should be given to how a limited resource such as the Queensland east coast Spanish mackerel stock that supports the ECSMF should be shared among competing sectors in a dynamic environment. While participation in the commercial sector of the fishery wanes, the recreational sectors participation continues to increase. The current separation of commercial TAC and a recreational bag limit as two isolated management strategies does not control total annual landings taken from the ECSMF. Attention must be paid to the increasing effort and catch of the recreational sector, and consideration given to the best management tools to prevent a burgeoning fisheries (recreational) sector negatively impacting another sectors (commercial sector).

Improved data collection by the commercial fishery would also significantly assist future monitoring actions and management decisions. The current spatial resolution of data recording does not allow harvested catches to be assigned to individual reefs. While the status of the resource remains uncertain and Spanish mackerel aggregations and thus fishing effort and catch continues to be tightly associated with isolated reefs, knowledge of the spatial distribution of effort and catch among individual reefs is needed. If restricting the level of catch taken from within the spawning season is required in future years, quantification of individual reef importance to fishing effort and catch will be required.

Further development

The most pressing question raised as a result of the findings of this project is how Spanish mackerel distributes themselves among the spawning reef complex each spawning season? The behaviour identified via the acoustic monitoring suggests reef –fidelity is high within years; does that behaviour extend to among years? Is it possible that philopatric behaviour occurs? If these types of behaviours do occur, serial depletion of the Spanish mackerel population is possible, and will be difficult to detect via commercial catch statistics because of the hyper-stable tendencies of this data.

To completely understand the importance of and potential impacts of fishing on, the annual spawning aggregations that form on the Townsville reefs knowledge of the origin of the participating mackerel would be helpful. Do the mackerel that aggregate on the Townsville Reefs travel from far and wide, or alternately do they only represent a proportion of the east coast population. Similarly, do other spawning reefs or reef complexes exist though are not yet known to fishers? If they do, given the current status of the Townsville aggregations and the extirpation of the Cairns aggregations, other aggregations may need to be afforded a high level of protection.

While the Townsville Reefs fishery is mostly a commercial fishery, the southeast Queensland fishery is dominated by the recreational sector. A combination of increased participation and effort creep through gear technology advances, there is concern about the level of effort and catch of the recreational sector. Although the recreational fishery largely occurs during non-spawning months, during these non-spawning months Spanish mackerel still demonstrate obligate and transient aggregating characteristics that make them vulnerable to fishing (Tobin et al 2013). The aggregating behaviours of Spanish mackerel away from the spawning grounds and outside of the spawning season should be investigated. As bag limits may be an ineffective management tool for controlling recreational catch (Cox et al 2002), spatial and or temporal closures may be the most effective tool for limiting recreational harvests.

Extension and Adoption

Chronologically the project was extended and communicated to stakeholders in the following ways:

November 2010 – Queensland Seafood Magazine (see Appendix D)

The existence, background and goals of the project were identified in a short easy to read and digest piece for the Queensland Seafood magazine. The audience for this medium is largely the commercial fishing industry, though is also read by managers and other stakeholders (conservation, recreation) of Queensland's fisheries.

November 2010 and 2011 – Project generated flyer (see Appendix E)

Project staff developed an easy to read and digestible flyer to disseminate through the commercial fishing fleet that participated in the spawning aggregation fisheries of 2010 and 2011. The dissemination of this flyer occurred through opportune meetings on the water, at the wharf and via staff of QDAFFs LTMP for Spanish mackerel that have staff on some commercial fishing vessels during the spawning aggregation fishery.

February 2012 – Escape with ET (see Appendix F)

The project was highlighted in the Escape with ET television series (Series 13, Program 11) that is widely viewed by fishers from all fishing sectors. The segment included a concise brief on the need, objectives and methods of the project as well as some preliminary results.

November 2012 – Conference presentation – **Oceans Past IV**, Fremantle.

Project staff Sarah Buckley oral presentation of - "Unravelling the history of a spawning aggregation fishery: is Queensland fish and chip shop fish on the verge of collapse?" (see Appendix G)

August 2012 – Final Project Workshop

Final Project Workshop (held at James Cook University, 24th August 2012) was attended by both GBRMPA and QDAFF managers including Randal Owens, Darren Cameron, Rachel Pears and Brigid Kerrigan. Two fishing industry representatives invited to the meeting (Carl DeAguire, Shaun Hanson) were unable to attend.

Brigid Kerrigan (QDAFF) gave a verbal brief of the recent stock assessment for the Queensland east coast Spanish mackerel fishery (Campbell et al 2012). There is some uncertainty about the outputs, however one scenario estimates the east coast Spanish mackerel fishery is ***fully fished***. While the commercial TAC remains under-caught, this has generated significant concern from fishers and managers alike.

The participants were briefed on the final outputs of the acoustic monitoring component of the project. Given the results of two years of acoustic monitoring, considerable discussion focused on what future management strategies (time and/or area closures) should be modelled.

August 2013 – Project results disseminated and shared with stakeholders of the Torres Straits Spanish mackerel fishery including AFMA managers as well as traditional and non-traditional commercial fishers. In response to similar concerns within the Torres Strait regarding the current status of the fishery, potential increased participation in future years, an uncertainty about the suitability of current TACC and the vulnerability of a fishery that targets a spawning aggregation the project PI undertook an information sharing workshop and discussed the applicability of the Queensland east coast research outcomes to the Torres Strait fishery.

August 2014 – Conference presentation – **International Marine Conservation Congress**, Glasgow, Scotland.

Project staff Sarah Buckley has also been accepted for an oral presentation of - "Historical reconstruction of commercial and recreational spatio-temporal patterns reveals a Great Barrier Reef spawning fishery in double jeopardy?" (see Appendix H)

Project outputs adopted :

One of the main project outputs and recommendations – the need to explicitly consider the allocation of the Spanish mackerel fishery amongst commercial and recreational sectors - will be considered by the recently funded FRDC TRF Project 2013/230 – *Defining a resource sharing option in a multi-sectoral fishery: using the Queensland Coral Reef Finfish Fishery as a test case*. In response to the identification through this project, and that of Tobin et al (2013) as well as Campbell et al (2012), the critical need to derive better estimates of recreational harvest subsequent to developing a resource sharing allocation strategy for the ECSMF must occur with some urgency. The funded TRF project will provide a vehicle for the consideration of sharing a finite resource among the changing demands of competing fishery sectors.

Project coverage

The project was covered by television media (Escape with ET – see Appendix F) and an industry article (Queensland Seafood magazine – see Appendix D).

Project materials developed

The project developed a factsheet that was targeted towards commercial fishers with an active participation in the contemporary spawning aggregation fishery. This fact sheet is included as Appendix E.

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Appendix A Intellectual Property

No patentable or marketable products or processes have arisen from this research. All result will be published in scientific and non-technical literature. The raw data from compulsory fishing logbooks remains the intellectual property of QDAFF. Raw catch data provided by individual fishers remains the property of the fishers. Intellectual property accruing from the analysis and interpretation of raw data rests jointly with JCU and QDAFF.

Appendix B Researchers and project staff

Andrew Tobin	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Amos Mapleston	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Alastair Harry	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Jonathon Smart	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Steve Moore	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Colin Simpfendorfer	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Michelle Heupel	Australian Institute of Marine Science, and Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Sarah Buckley	ARC Centre of Excellence for Coral Reef Studies and School of Biological Sciences, University of Queensland
Ruth Thrustan	ARC Centre of Excellence for Coral Reef Studies and School of Biological Sciences, University of Queensland
John Pandolfi	ARC Centre of Excellence for Coral Reef Studies and School of Biological Sciences, University of Queensland

Appendix C Semi-structured interview with Spanish mackerel fishers

Experience

What year did you first begin fishing?

When did you start fishing regularly?

Do you still fish today?

If not, when did you cease fishing?

(If commercial operator) How long have you been fishing commercially?

Who taught you to fish?

(If not taught by family) Did anyone in your family commercially fish before you?

Spawning Fishery

Present Fishing Experience

What months do you fish for Spanish mackerel?

How many days per week do you go fishing, on average?

How many hours do you typically fish for?

What depth do you fish at?

Where do you regularly fish now? (please mark on map)

- Please draw your fishing sites and any known spawning sites
- OR, provide fishing ground names/distance from shore
- Please draw on the map where (target species) is most abundant. The abundance categories are 10 = most abundant and lower values correspond to relative abundance

How many Spanish mackerel do you catch on a 'good' day?

How many Spanish mackerel do you catch on a 'normal/average' day?

How many Spanish mackerel do you catch on a 'poor' day?

Past Fishing Experience

How often did you go fishing?

What months did you typically fish?

How many days per week did you fish, on average?

How long were your trips on average?

How many hours do you typically fish for?

What depth did you fish at?

Where did you regularly fish? (please mark on map)

- Please draw the fishing/spawning sites
- OR, Fishing ground names/distance from shore
- Please draw on the map where (target species) is most abundant. The abundance categories are 10 = most abundant and lower values correspond to relative abundance

How many Spanish mackerel do you catch on a 'good' day?

How many Spanish mackerel do you catch on a 'normal/average' day?

How many Spanish mackerel do you catch on a 'poor' day?

Past Catches / Trends over Time

Can you remember, when was your best season for catch?

What was the most consistent fishing you have experienced? (eg: I have experienced week long "bites" of 50 plus fish / day)?

Did your effort change during that season?

Can you remember good, poor and normal catches during these events?

Memorable events	Year	Good catch	Normal Catch	Poor Catch	Hours fishing
1974 Flood					
Marriage					
Child's Birth					
Log Books 1988					
Introduction of Zones (2004)					
Green Zones Moreton Bay (2009)					
Introduction of TAC					
Sale of recreational fish outlawed (90)					

Have you ever fished in the Spanish mackerel spawning fishery?

If yes, Changes in effort/catches -

(eg: prior to RAP I used to fish 3 dories and October and November only; post-RAP I have only fished the main boat and now fish September through to December, introduction of GPS, vessel change, gear change?

Do you remember when (if) you noticed changes in effort, were these changes sudden or gradual?

What were the drivers of these changes?

Can you remember, when was your best season for catch?

What was the most consistent fishing you have experienced? (eg: I have experienced week long “bites” of 50 plus fish / day)?

Did your effort change during that season?

Perceptions of Change

Has the abundance of Spanish mackerel increased, decreased or stable since you began fishing?

When did you notice the change?

To what extent?

Has the size of Spanish mackerel increased, decreased or stable since you began fishing?

When did you notice the change?

To what extent?

How would you describe the health of east coast Spanish mackerel today? 1- 5 scale.

If your fishing locations changed during your career, what do you think caused this change?

Have any management actions changed your experience of fishing Spanish mackerel?

If so, in what way?

Did you notice a change in the number of vessels targeting the spawning Spanish mackerel fishery

a) What and when was the maximum number of vessels fishing in your fishery

b) When did the number of vessels decline

c) Why did these vessels leave the fishery

What do you see are the threats to the fishery?

Appendix D Spanish mackerel research update

(Published in the Queensland Seafood Magazine, Nov 2010)

Spanish mackerel research update

A new Spanish mackerel fishery research project has recently begun on the Queensland east coast. The research will estimate how much protection is afforded to Spanish mackerel by the current Marine Park zoning. Determining the level of benefit offered by Marine Park zoning to the Spanish mackerel fishery is a recommendation for future WTO certification of the fishery by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPC)(previously known as the Department of Water, Heritage and the Arts – DEWHA)(see http://www.dpi.qld.gov.au/documents/Fisheries_SustainableFishing/EastCoast-SpanishMackerel-RecsAndConds-2009.pdf).

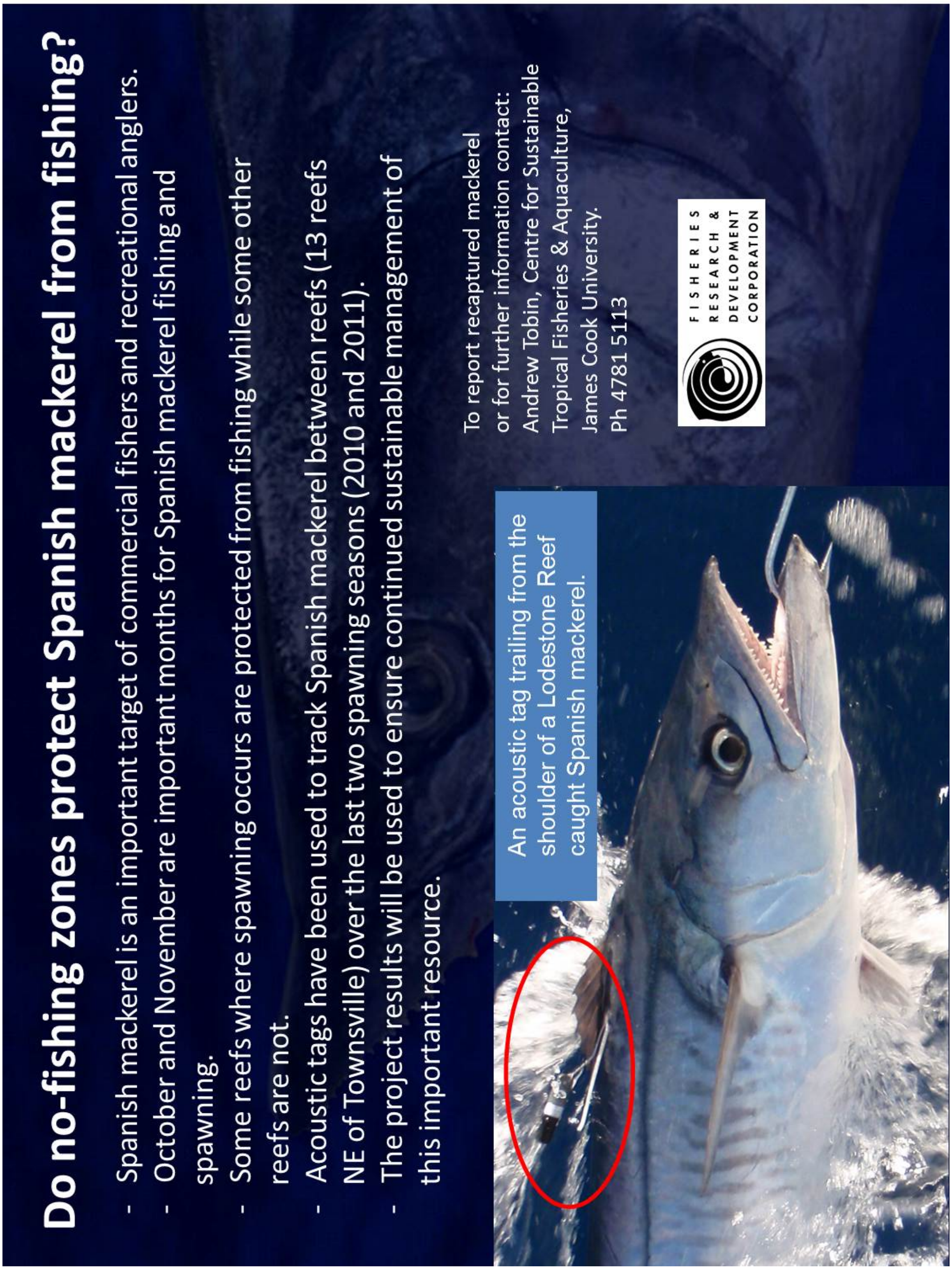
To measure how much time Spanish mackerel spend in protected zones of the Great Barrier Reef, individual mackerel will be tagged with acoustic transmitters during the spawning seasons of 2010 and 2011. Acoustic receivers will detect the presence of the tagged mackerel when they swim past or aggregate at certain reefs. In 2010, acoustic receivers have been placed on fished reefs (Rib, John Brewer, Lodestone, Keeper, Centipede and Davies) as well as protected reefs (Wheeler, Helix and Kelso). The data collected by the receivers will allow the time mackerel spend in different marine park zones to be estimated.

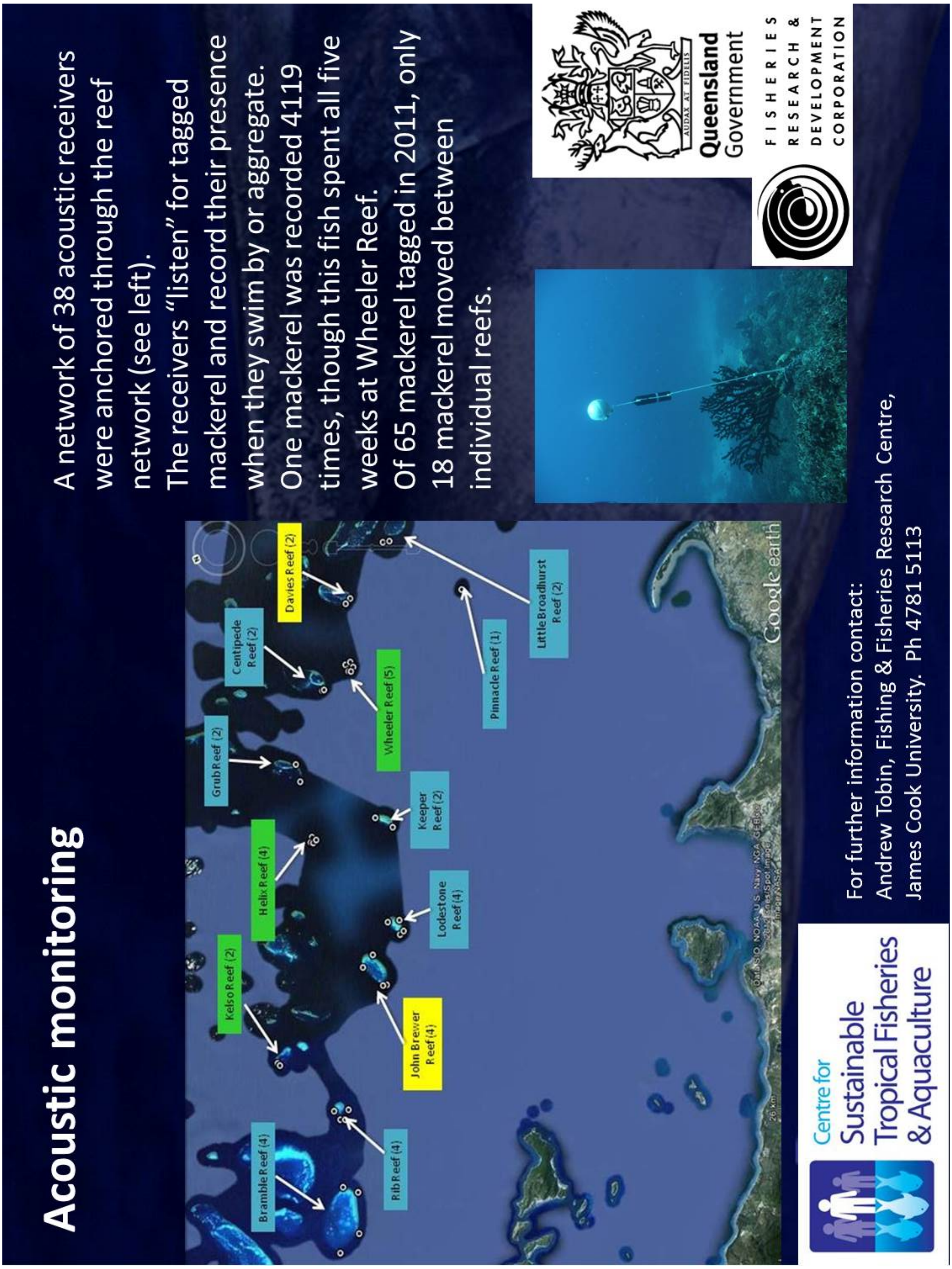
The data will be used to build greater certainty into the future management of the fishery at a time when commercial participation is ever decreasing and recreational participation continues to increase. The research is also hoping to document why participation in the commercial fishery is at an all time low. Project staff would like to talk with fishers with extensive history in the fishery to document fishers' thoughts on the state of the fishery.

Commercial fishers are asked to keep an eye out for tagged mackerel with a reward offered for recapture information. This research has been supported by both Fisheries Queensland and QSIA. Andrew Tobin can be contacted on 4781 5113 or Andrew.Tobin@jcu.edu.au for further information.

Appendix E Project fliers

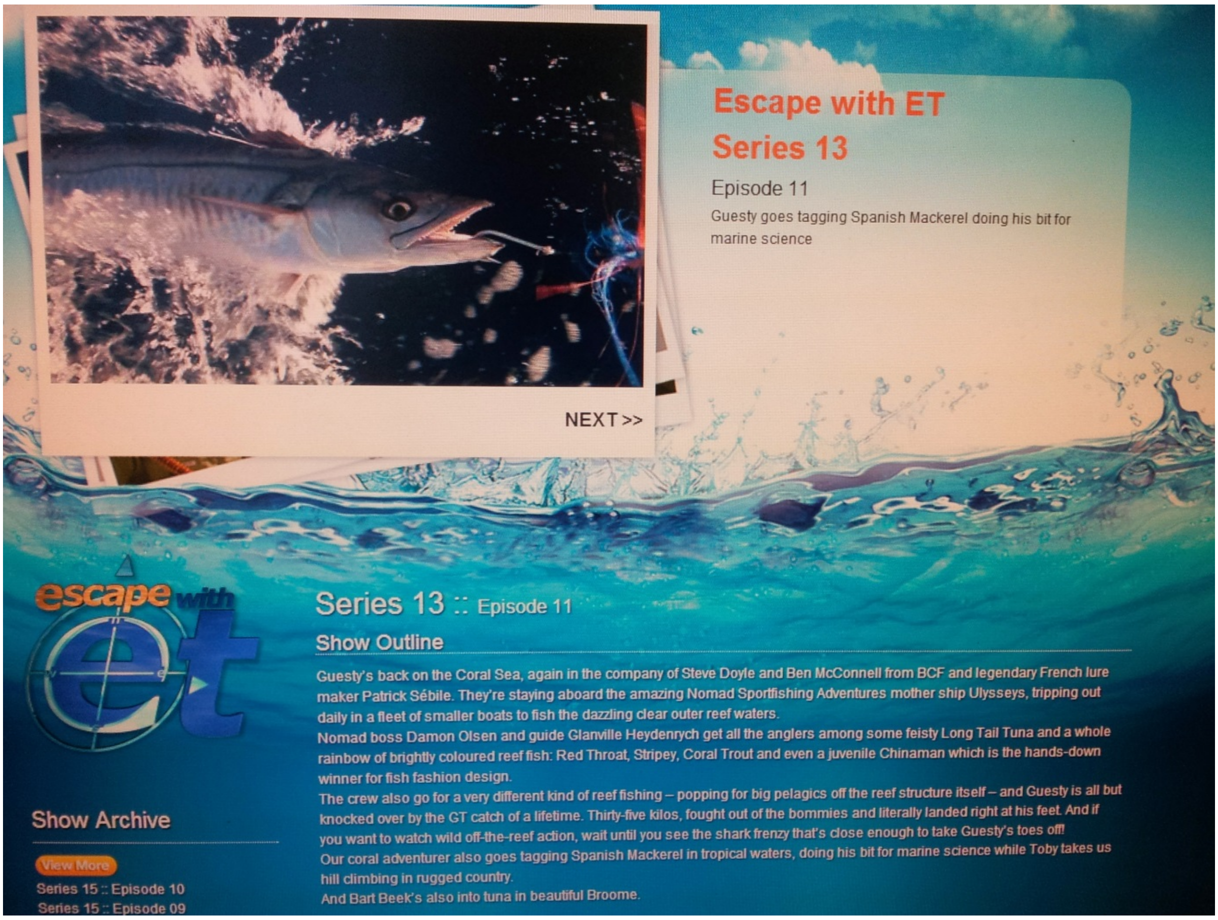
These project fliers were distributed to fishermen opportunistically through wharf and on-water meetings and via the QDAFF Long-Term Monitoring Project staff who work closely with fishers who access the spawning aggregation fishery.




Acoustic monitoring
Bramble Reef (4)
Rib Reef (4)
Kelso Reef (2)
John Brewer Reef (4)
Helix Reef (4)
Lodestone Reef (4)
Keeper Reef (2)
Grub Reef (2)
Wheeler Reef (5)
Centipede Reef (2)
Pinnacle Reef (1)
Davies Reef (2)
Little Broadhurst Reef (2)
Google earth
A network of 38 acoustic receivers were anchored through the reef network (see left).
The receivers "listen" for tagged mackerel and record their presence when they swim by or aggregate.
One mackerel was recorded 4119 times, though this fish spent all five weeks at Wheeler Reef.
Of 65 mackerel tagged in 2011, only 18 mackerel moved between individual reefs.
Queensland Government
FISHERIES RESEARCH & DEVELOPMENT CORPORATION
Centre for Sustainable Tropical Fisheries & Aquaculture
For further information contact:
Andrew Tobin, Fishing & Fisheries Research Centre,
James Cook University. Ph 4781 5113

Appendix F Escape with ET coverage

The project was also extended to the recreational fishing and broader community through a story run on the popular fishing program Escape with ET (Series 13, Episode 11). The program included the opportunity to share the project background, objectives, methods and preliminary results to the viewer.



Appendix G Conference presentation – Oceans Past IV, 2012

Unravelling the history of a spawning aggregation fishery: is Queensland's fish and chip shop fish on the verge of collapse?

Sarah Buckley[1], Ruth Thurstan[1], Andrew Tobin[2] and John M. Pandolfi[1]

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ABSTRACT

The management of Australian fisheries in general is dependent on statistics limited to less than one human generation, however, intensive fishing commenced in parts of Australia during the late 19th century. Evidently without a historical perspective baseline populations and current status of species is underestimated. The narrow barred Spanish mackerel (*Scomberomorus commerson*) represents a pelagic transient spawning aggregating species and is one of Queensland's most valuable fish species. Our case study focuses on the East Coast stock, where commercial fishing has targeted the spawning season as well as the predictable migratory route for generations. Anecdotally the fishery is described as being on the verge of collapse, yet in the most recent stock assessment Spanish mackerel was declared sustainable. However, the assessment failed to include long-term abundance indices or changes in fishing power and effort over time, hence masking of hyperstability is of great concern.

This study will try and fill those gaps using an innovative multi-disciplinary approach involving historical, social and fishery methods to ascertain the true status of Spanish mackerel. A reconstruction of time series of catch rates over multiple generations is being extracted from newspaper archives, oral histories, personal log books and fishery statistics in order to describe the temporal and spatial trends of Spanish mackerel abundance throughout its fishing history. We aim to encompass the effects of the intensification of fisher behaviour on the spawning aggregation during the early 20th century and the growth of the commercial Spanish mackerel fishery along the coast of Queensland. Changes in effort and power are being obtained from commercial operators targeting both the spawning season and the migratory route of Spanish mackerel through standardised oral histories to determine the impact of evolving fishing technologies, fishing effort and changing management regimes upon fish catches and abundance over time.

The reconstruction of major periods of decline over multiple generations will demonstrate the importance of historical baselines and the valuable data these non-conventional methods provide. The applied use of local knowledge combined with historical reconstructions of catch rate and fishing effort can equip managers with a useful tool to improve the accuracy of current stock assessments. A comparison of past abundance data and present trends is necessary and will be important in reducing the uncertainties in setting appropriate management targets and ensuring the future sustainability of the east coast Spanish mackerel fishery. This is of particular importance for pelagic and transient aggregating spawning fisheries, whose stocks are of concern globally due to heavy fishing pressure on these key fisheries.

Appendix H Conference presentation – International Marine Conservation Congress, 2014

Historical reconstruction of commercial and recreational spatio-temporal patterns reveals a Great Barrier Reef spawning fishery in double jeopardy

Sarah M. Buckley[1*], Ruth H. Thurstan[1], Andrew Tobin[2], John M. Pandolfi[1]

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Fish spawning aggregations (FSAs) support productive and valuable fisheries yet are extremely vulnerable to overexploitation and depletion. Assessment and subsequent management of FSA fisheries requires analysis of long-term spatio-temporal trends in fishery catch and effort to overcome shifting baselines. We compile newspaper archives, fisher knowledge, and contemporary catch logs to reconstruct a century-long commercial catch time series for Australia's Great Barrier Reef Spanish mackerel FSA fishery (1911-2011). After correcting for changes in fishing power and effort, average catch rates were found to decline nearly 3-fold, from 140 to 40 fish vessel^{-1} trip^{-1} between 1934 and 2011. Spatial effort contracted to just 22% of FSA areas presumably as FSAs were extirpated. Fishers travelled further offshore from traditional spawning grounds due to the commercial extinction of the northern spawning fishery, declining catch rates and the incursion of recreational effort. Recreational fishers targeting historic inshore spawning grounds since 1970 are unaware of spawning aggregations, indicating the disappearance of spawning components. Retrospective evaluation of the spatio-temporal dynamics of the Great Barrier Reef Spanish mackerel spawning fishery reveal gross changes in the spawning patterns and productivity that are not evident in contemporary records. We provide empirical evidence relevant for effective management and the long-term sustainability of FSA fisheries.