Queensland **Primary Industries and Fisheries**

Coral reef fin fish spawning closures

Risk assessment and decision support

Report on outcomes from a workshop held 12–13 May 2009

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THE UNIVERSITY OF MELBOURNE

Queensland Government

On 26 March 2009, the Department of Primary Industries and Fisheries was amalgamated with other government departments to form the Department of Employment, Economic Development and Innovation.

Acknowledgments

We thank all those who attended the workshop. Tracy Rout and John Kung assisted in analyses and reporting. The structure and content of the workshop benefited from discussion with Jan Carey.

Contents

Summary

A 2-day workshop involving scientists, managers and stakeholders explored 6 candidate alternatives for spawning closures to be applied to the coral reef fin fish fishery from 2009 to 2013.

The perceived merit of any single alternative rests on:

(a) *biological judgments* concerning its capacity to protect important fish species

(b) *value judgments* concerning trade-offs between protection, costs to fishery users, and other relevant considerations.

Participants varied in their judgments of both elements. Variation in biological judgments arises from uncertainty in scientific knowledge. Variation in value judgments reflects the priorities and preferences of individuals and organisations. The workshop integrated both elements in a structured decision-making framework.

The following criteria were used to assess the relative merit of each alternative:

- maximise protection of fish species
- minimise costs to fishers (commercial, recreational and charter)
- maximise broader ecosystem benefits
- maximise ease of enforcement
- maximise opportunities to learn the effect of spawning closures on fish protection and the broader ecosystem.

In assessing alternatives against these criteria, participants dealt with trade-offs. Collective compromises identify one or more alternatives that participants regard as broadly acceptable, rather than an alternative that is optimal for any subset of stakeholders or objectives.

Coral trout was seen to be the most important species group among coral reef fin fish (CRFF). Participants generally agreed that spawning closures provided added protection to coral trout, and that the magnitude of protection depended on the specific closure regime. There was less agreement on the need for additional protection above that provided by other management arrangements in place.

Across all criteria there was no clear or compelling collective preference for any of the six candidate alternatives. Some alternatives attracted distinctly divergent views. Two alternatives were broadly acceptable to most participants:

Alternative 3

Five years of 5-day closures to be applied in each of October and November.

Closures refer to all species.

Alternative 6

Five years of 5-day closures to be applied in each of October and November, plus

a 5-day September closure *if* the new moon falls after the 15th day of that month, and a 5-day December closure *if* the new moon falls before the 15th day of that month.

Closures refer to coral trout *only*.

Along with the formally captured views of participants, the decision-maker will have to give due consideration to other information, including the workshop discussions that form part of this report and criteria that were addressed only coarsely (ecosystem benefit, enforceability and prospects for learning).

We note the following regarding Alternative 3:

- It is among the best options for protection of coral trout, red emperor, large mouth nannygai, spangled emperor and camouflage cod/flowery cod.
- Protection is afforded to all coral reef fin fish; therefore, catch and release of coral trout while fishing for other species will be minimised as will disruption to spawning fish.
- Alternative 3 imposes a relatively low impact on all fishery sectors and the ecosystem benefits and ease of enforcement are moderately high.

We note the following regarding Alternative 6:

- It provides a relatively high level of protection to coral trout.
- The inclusion of specific ‘if–then’ configural rules relating to lunar phase in September and December represents a more sophisticated biologically-based, cost-effective approach to protection than the status quo.
- It is the worst alternative with respect to ‘ease of enforcement’.
- Its effectiveness as a protective measure rests on high survivorship of caught and released coral trout and assumes minimal disruption to spawning fish as a result of fishing.

Introduction

A two day workshop explored candidate alternatives for spawning closures to be applied to the coral reef fin fish fishery from 2009 to 2013. Participants are listed at Appendix 1.

Participants nominated 12 candidate closure regimes (Table 1). Time constraints meant that only 6 of these could be considered in detail. 'No closures' was made a mandatory inclusion in the shortlist so that the relative impact of other candidates could be gauged against a 'do nothing' baseline. The remaining 5 were selected by votes cast by participants. All candidates refer to closures around the new moon.

The merit of any single alternative rests on:

(a) *biological judgments* concerning its capacity to protect important fish species

(b) *value judgments* concerning trade-offs between protection, costs to fishery users, and other relevant considerations.

Experts and stakeholders vary in their judgments of both elements. Variation in biological judgments arises from uncertainty in scientific knowledge. Variation in value judgments reflects the priorities and preferences of individuals and organisations. The workshop integrated both elements in a structured decision-making framework.

Table 1. Alternative closure regimes nominated by participants.

Shortlisted alternatives	Non-shortlisted alternatives
A1 No closures.	5 years with 1 × 90-day closure in October, November and December. Commercial fishery only.
A2 2 years no closures, followed by three years with 2 × 9-day closures in October and November.	5 years with 3 × 9-day closures in October, November and December.
A3 5 years with 2 × 5-day closures in October and November.	5 years with 3 × 5-day closures in October, November and December.
A4 5 years with 2 × 9-day closures in October and November, offshore charter exempt, no offshore charter activity 20 December–31 January.	5 years with 3 × 7-day closures in October, November and December. Coral trout only.
A5 5 years with 2 × 9-day closures in October and November (status quo).	5 years with 7-day closure in October 5-day closure in November, plus 5 days September closure if new moon after 15th 5 days December closure if new moon before 15th.
A6 5 years with 2 × 5-day closures in October and November, plus 5 days September closure if new moon after 15th, 5 days December closure if new moon before 15th, coral trout only.	5 years 2 × 5-day closures October and November, plus 5 days September closure if new moon after 15th 5 days December closure if new moon before 15th.

Methods

Two interacting flaws commonly encountered in risk assessment protocols are (a) separating risk assessment from risk management, thus disrupting essential connections between social values and the scientific knowledge necessary to predict the likely impacts of management actions, and (b) relying on expert judgment about risk framed in qualitative and value-laden terms, inadvertently mixing the expert's judgment about what is likely to happen with personal or political preferences. To buffer against these flaws, we used a probabilistic approach to cause-and-effect and multi-criteria analysis to describe and weigh social and organisational values (Maguire 2004). We incorporated the views of experts and stakeholders in an effort to overcome the motivational and cognitive biases of individuals (Failing et al. 2007).

Biological judgments

Figure 1 records participants' collective perceptions of the importance of each species/species group to conservation and the commercial, recreational and charter fisheries. While the importance of individual species (or species groups) to the three fisheries varied substantially, importance to conservation was notably invariant. Depending on the interpretation of individual participants, 'conservation' may imply intrinsic values or instrumental value for humans (Justus et al. 2009). The workshop did not define conservation values in any detail, leading to language-based ambiguity (Regan et al. 2002). Nevertheless, the consistency in importance ratings across species suggests most participants regarded intrinsic value to be a primary concern.

Based on these outcomes participants agreed to the following shortlist of species for further consideration in the workshop:

- coral trout[1] (*Plectropomus* spp. and *Variola* spp.)
- red throat emperor (*Lethrinus miniatus*)
- red emperor (*Lutjanus sebae*)
- large mouth nannygai (*Lutjanus malabaricus*)
- spangled emperor (*Lethrinus nebulosus*)
- camouflage grouper/flowery cod (*Epinephelus polyphekadion* and *E. fuscoguttatus*; to be considered together).

For each alternative closure regime and each species, participants were individually asked to estimate the probability (%) that fish numbers encountered in Great Barrier Reef Marine Park general use and habitat protection zones ('blue zones') over the past five years will be maintained over the next five years. That is, given hypothetical implementation of alternative *x*, what is the chance the number of fish of species *y* is maintained or increased over at least half of all blue zone reefs? Responses assumed all other management controls (e.g. quota, bag limits, green zones) remain unchanged from current conditions.

The point estimates of individuals ignore uncertainty. To derive a plausible interval on probabilities, we pooled the judgments of multiple experts and stakeholders (Armstrong 2001, Yaniv 2004). We considered a plausible interval to be one that encompassed the estimates provided by nine of the 13 participants.

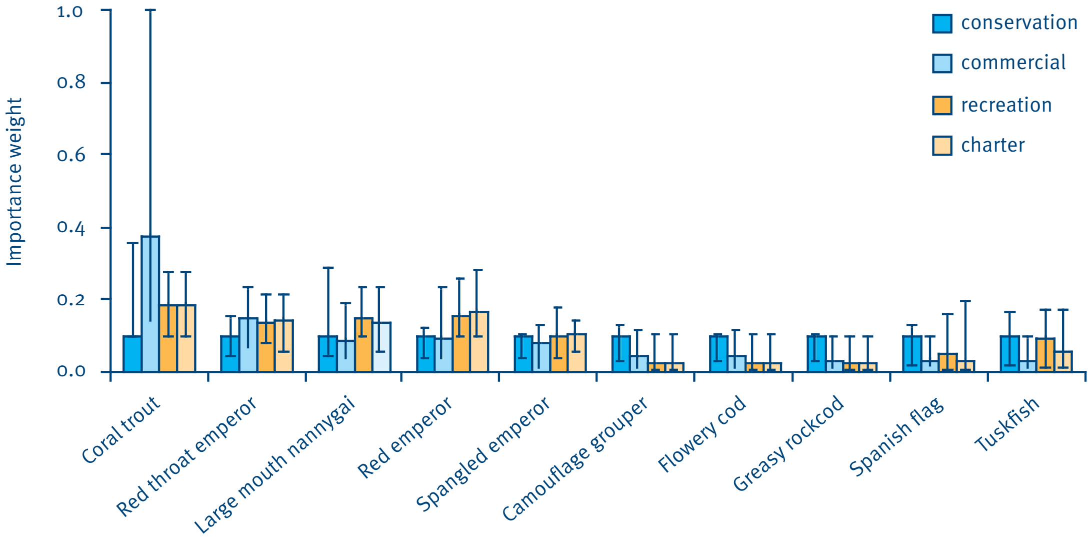

Figure 1. The median importance of coral reef fin fish species. Error bars indicate the full range of responses among 14 participants.

1. Consideration and assessment of coral trout focused on common coral trout (*P. leopardus*) as the primary species and the species with the most available biological information.

Combining biological and value judgments

Multi-criteria analysis (MCA) assesses alternatives by eliciting judgments from people about the relative importance of personal, organisational or societal values. The basic steps are:

- create a list of objectives (decide on criteria and sub-criteria relevant to the decision problem)
- identify management alternatives (options)
- identify measures of performance for each criterion
- assign performance scores to the criteria
- specify weights for criteria
- aggregate the scores, and evaluate the sensitivity of outcomes to weights and scores.

MCA can be effective for complex decision problems that include market and non-market values (Hajkowicz 2008). The objectives are used to order thinking about important attributes (criteria), to ensure no important elements are overlooked, that criteria are meaningful and decomposable, and to avoid redundancy in judgements (Keeney and Raiffa 1976).

The protection of coral reef fin fish species is not the only consideration in the decision problem. Implicit in the shortlist of alternatives is recognition that protection needs to be weighed against costs to fishers, among other criteria. Participants identified the following criteria:

- maximise protection of fish species
- minimise costs to fishers (commercial, recreational and charter)
- maximise broader ecosystem benefits
- maximise ease of enforcement
- maximise opportunities to learn the effect of spawning closures on fish protection and the broader ecosystem.

In assigning weights to these criteria, participants deal with trade-offs that usually involve outcomes that do not see maximisation (or minimisation) of objectives. Collective compromises seek to identify one or more alternatives that participants regard as broadly acceptable, rather than an alternative that is optimal for any subset of stakeholders or objectives.

Results

Biological judgments

After providing initial estimates of the probability of maintaining the number of fish in blue zones over the next five years, participants were invited to justify and cross-examine each others' perspectives. Estimates were then revised in the light of discussion. Results of revised estimates for each species are shown in Figure 2.

Among the candidate alternatives considered, the species most sensitive to spawning closures is coral trout. It is also the most important to fishery users (Figure 1). Median estimates range from a 70% chance of maintaining fish numbers under no closures (Alternative 1) to 90% under Alternative 6. A more conservative (risk-averse) assessment places greater emphasis on lower bounds. Ignoring outlier responses (i.e. the whiskers in Figure 2), Alternatives 4, 5 and 6 all appeal to a risk-averse decision-maker. They have high lower bounds.

For the species of lesser (but non-trivial) importance, Alternatives 3 and 5 are sound risk-averse options when considering red emperor, large-mouth nannygai, spangled emperor and camouflage grouper/flowery cod. Red throat emperor is essentially insensitive to the 6 alternative spawning closures because it spawns mainly in winter, outside any of the periods included in any of the alternatives.

Combining biological and value judgments

The estimated performances of the alternatives under each criterion are shown in Table 2. Protection was described as 'chance of successful maintenance of fish numbers', described above. Intervals equate to the plausible bounds plotted in Figure 2 (i.e. the boxes, ignoring outlier 'whisker' responses). The cost to each fishery sector was estimated by participants as fishing days lost over the 5-year regime. Again, uncertainty is characterised using an interval. The three criteria dealing with ecosystem benefits, ease of enforcement, and prospects for learning were scored on an arbitrary Likert scale from 1 (worst) to 4 (best).

Each of the 13 participants assigned weights to the 12 criteria shown in Table 2. The weight apportioned to any criterion reflects both the importance of the criterion and the full range of raw performance scores associated with alternatives (Steele et al. 2009).

Decision scores for each participant and each alternative were obtained using simple weighted summation (Keeney and Raiffa 1976). That is, the decision score V for alternative i is,

$$V_i = \sum_{j=1}^{n} w_j X_{ij}$$

where w_j = weight for criterion j, and X_{ij} = normalised score for alternative i on criterion j.

Table 2. Estimated performance of each alternative against identified criteria.

Criterion	Preferred direction	A1	A2	A3	A4	A5	A6
Chance (%) of 'protecting'							
Coral trout	More	29–80	35–85	50–85	66–90	69–90	62–90
Red throat emperor	More	28–96	41–96	25–96	25–95	25–96	34–96
Red emperor	More	30–90	50–90	50–91	49–90	50–91	35–91
Large mouth nannygai	More	30–90	50–90	50–90	48–90	50–90	35–90
Spangled emperor	More	44–95	50–95	50–95	50–95	50–95	44–91
Cam group/flow cod	More	29–90	39–90	49–95	49–95	50–95	40–90
'Effective' days lost to commercial fishing	Less	0	60–66	50	100–110	100–110	75
Recreational fishing	Less	0	54	50	90	90	0–5
Charter fishing	Less	0	54–60	50	100	90–100	20–30
Ecosystem benefits	More	1	2	3	4	4	2–3
Ease of enforcement	More	4	3.4	3	2.8	3	1
Prospects for learning	More	2–4	4	2	2	2	3

The importance of uncertainty in performance scores can be evaluated with sensitivity analysis. A simple approach is to conduct and compare separate analyses on plausible lower and upper bounds for the values reported in Table 2 (Burgman 2005). Results are shown in Figure 3.

Outcomes are largely insensitive to the uncertainty reported in Table 2. That is, the qualitative insights provided by lower bound calculations are consistent with those of upper bound calculations.

There is no clear or compelling collective preference for any of the six candidate alternatives. The large range associated with Alternatives 1, 4 and 5 (for both lower and upper bound calculations) imply that although their implementation is strongly supported by some participants, it would be strongly opposed by others. A less divisive approach is to consider implementing Alternative 2, 3 or 6. The 'Maxi-Min' strategy of decision-making under uncertainty appeals to those who are risk-averse. The strategy involves focusing on the minimum outcome associated with each alternative, and selecting the one with the largest minimum value (Morgan and Henrion 1990). The alternative with the largest minimum score is Alternative 6.

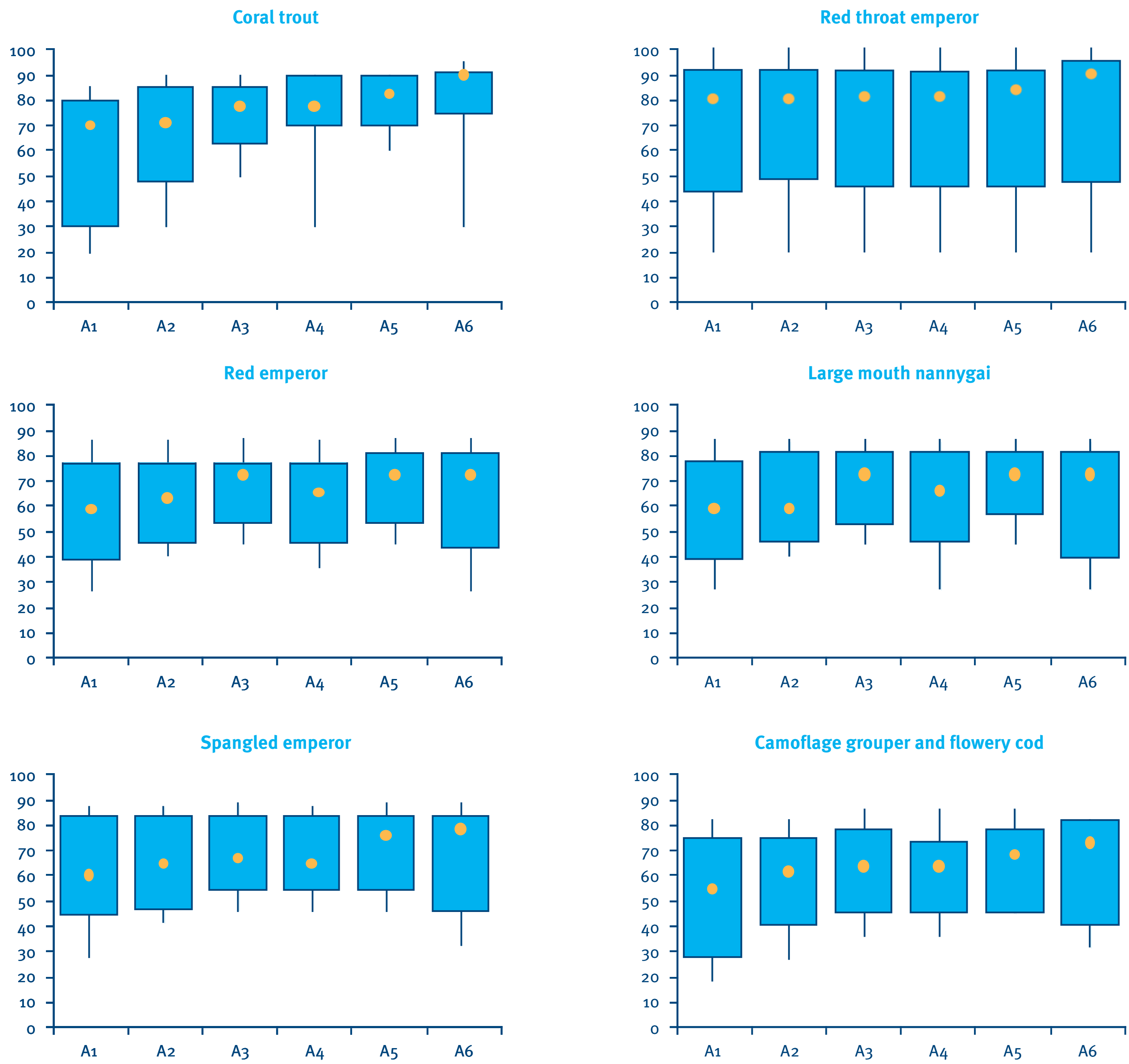

Figure 2. Participants' estimates of the chance (%) of maintaining fish numbers under 6 alternative closure regimes. Median response is indicated by a dot, the box shows the range of 9 of the 13 participants, and whiskers indicate the full range of the 13 participants.

The use and interpretation of Figure 3 assumes that the value judgments of all participants are equally relevant. This assumption is unlikely to be valid. There was no attempt to include proportional or full representation of stakeholders at the workshop. The decision scores of individuals (and the contributions of criteria to those scores) are recorded in Appendix 2.

The rank order of preference for each alternative among all participants is pooled in Figure 4. The distribution of rankings makes plain the divergence of views associated with Alternative 1 (no closures). Four of the 13 participants considered it the best option. Five considered it the worst. Contrasts were driven essentially by different emphases on losses to fishers and protection of species or broader ecosystem benefits. The breadth of opinion regarding the merit of Alternative 5 was likewise driven by these contrasting emphases (see Appendix 2 for details of the contributions of criteria to decision scores). Alternative 4 involved special arrangements for the charter sector. Seven participants rated it the worst option.

Alternative 6 had the broadest support. Ten of the 13 participants ranked it in their top three. One participant ranked it fourth best. Two ranked it fifth best. No-one considered it the worst option.

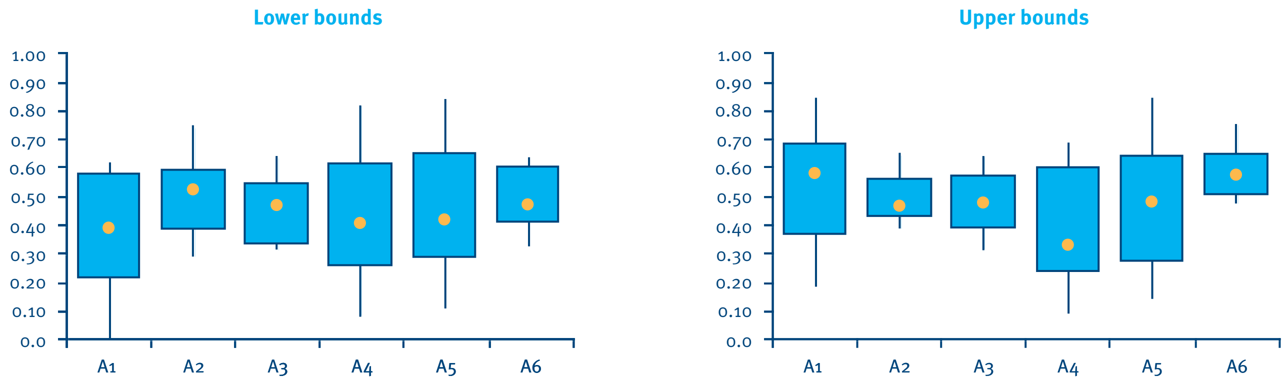

Figure 3. Participants' decision scores for the six alternatives. Lower (and upper) bounds refer to decision scores calculated using the lower (and upper) bound of performance score intervals reported in Table 2. Median score is indicated by a dot, the box shows the range of 9 of the 13 participants, and whiskers indicate the full range of the 13 participants.

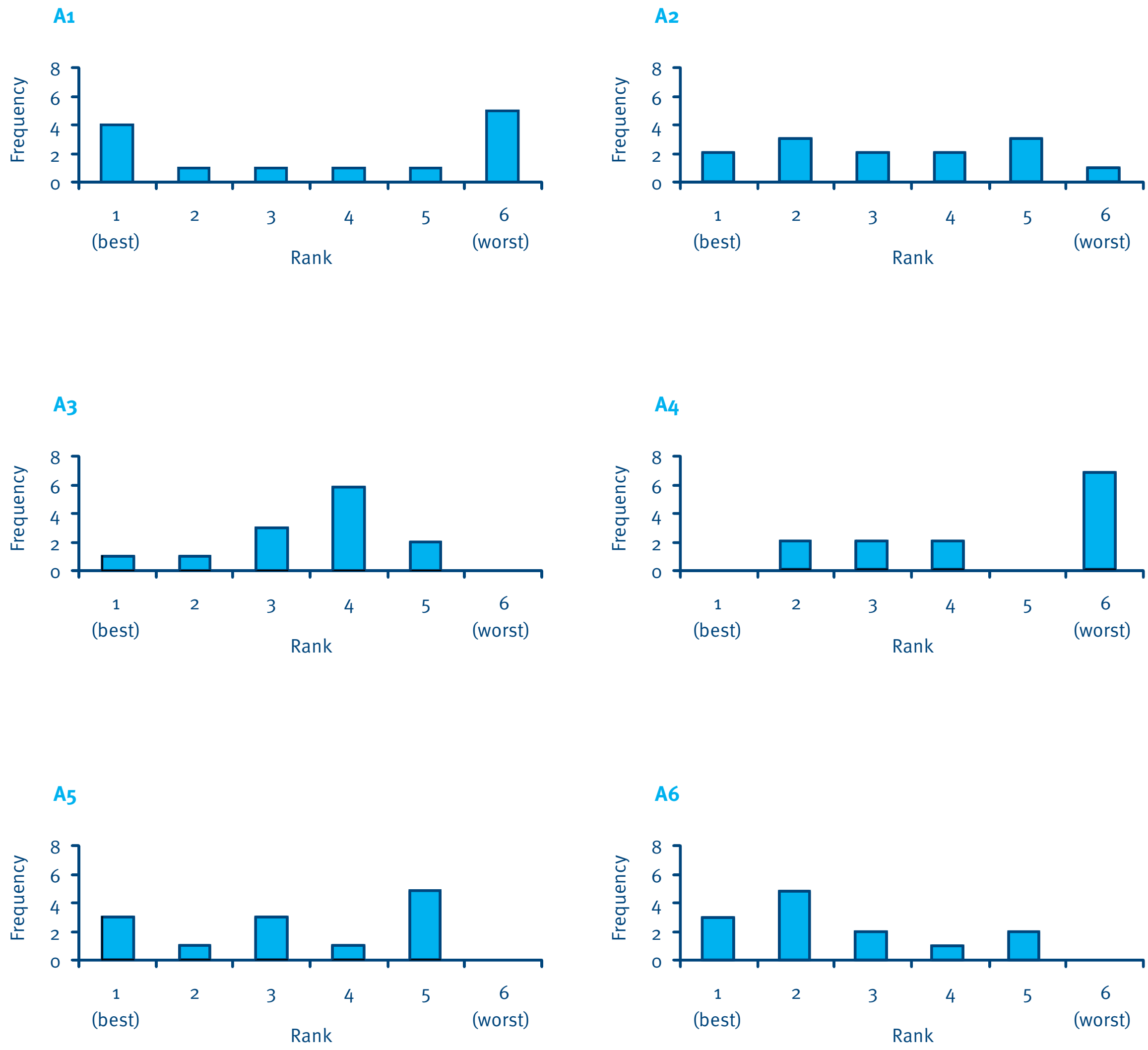

Figure 4. The frequency of rankings for each of the six alternatives among the 13 participants. Rankings were derived from the average of lower and upper bound calculations.

Discussion

In many circumstances, informal and imprecise processes are used to adjudicate on decisions in natural resource management. The approach adopted here provides a framework in which uncertainty may be characterised and carried through the logical steps that lead to a decision. A decision option that may yield a higher return might be declined in favour of an alternative with lower expected value but lesser uncertainty of outcome (Morgan and Henrion 1990). Decision-makers may choose to minimise potential adverse outcomes, to be risk-averse. Such decision-making under uncertainty can only be undertaken if the extent of uncertainty associated with alternatives is understood and communicated clearly. Sensitivity analysis explores the degree to which choices (decisions) might be affected by changes in the various elements of the decision structure.

Analyses were not without their limitations. Weighting is a demanding task. It requires participants to clearly understand the merit of each alternative against each criterion, and then assign weights that reflect personal or organisational trade-offs. In a relative sense, the indicators used to characterise performance associated with fish protection and costs to fishers were reasonably clear. The percentage chance of maintaining fish numbers, and days lost to fishing are natural and accessible indicators. But the assignment of weights may have been problematic for the three criteria assessed on an arbitrary four-point Likert scale.

The criterion *Ecosystem benefits* in part duplicated criteria pertaining to the protection of specific species. The protection of fish species is an end in itself for traditional fisheries management based around non-declining harvests. For conservation and broader ecological sustainability, the maintenance of fish species is only one component, or a means to a broader ecological end. The workshop did not directly address these complexities. It is likely that the failure to resolve underlying ambiguities in the inclusion of species-specific protection *and* broader ecosystem benefits lead to double counting (Keeney 2002).

These problems did not distort results substantially. Figure 5 shows decision scores after omitting 'ecosystem benefits', 'ease of enforcement', and 'prospects for learning'. Results are qualitatively similar to Figure 3. No single alternative is strongly recommended. Alternatives 1, 4 and 5 have large ranges. Alternative 6 would be marginally preferred over Alternative 3 if the 'Maxi-Min' strategy is used.

A more fundamental problem may have been incomplete listing of relevant objectives. Exhaustive elicitation of objectives is typically the most difficult step in MCA (Bond et al. 2008). The worst ranking assigned by seven of the participants to Alternative 4 (involving special arrangements for the charter sector) (Figure 4) may have been motivated by perceived inequities in the treatment of fishery sectors. Regulatory equity was not identified as an objective. Nevertheless, participants' judgments may have been coloured by their views on this issue.

While this report does not provide a clear and definitive outcome, it does provide the decision-maker with information on which to base a decision. Figure 5 illustrates the limitations associated with the adoption of Alternatives 1, 4 and 5, and to a lesser extent Alternative 2. Alternatives 3 and 6 provide more risk-averse options for consideration. Alternative 6 performed marginally better than Alternative 3 under the adoption of a 'Maxi-Min' strategy. Along with the formally captured views of participants, the decision-maker will have to give due consideration to other information, including the workshop discussions that form part of this report (Appendix 3) and the criteria that were removed from the adjusted decision scores (ecosystem benefit, enforceability and prospects for learning).

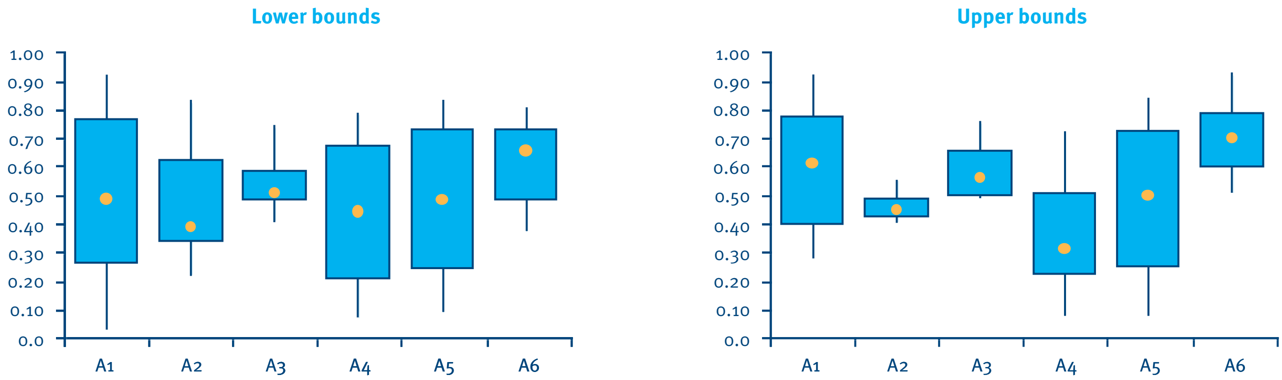

Figure 5. Adjusted decision scores, after removal of poorly characterised criteria ('ecosystem benefits', 'ease of enforcement', and 'prospects for learning'). Median score is indicated by a dot, the box shows the range of nine of the 13 participants, and whiskers indicate the full range of the 13 participants.

We note the following additional qualifications regarding Alternative 3:

- It is among the best options for protection of red emperor, large mouth nannygai, spangled emperor and camouflage cod/flowery cod (Figure 2), noting that there was very little difference between the alternatives for red throat emperor. There was also very little difference between Alternatives 3–6 in protecting coral trout.
- Protection is afforded to all coral reef fin fish, therefore catch and release of coral trout while fishing for other species will be minimised as will disruption to spawning fish. Those species other than coral trout that spawn around the new moons of October and November would be protected during periods of peak spawning activity.
- Alternative 3 imposes a relatively low impact on all fishery sectors and the ecosystem benefits and ease of enforcement are moderately high.

We note the following additional qualifications regarding Alternative 6:

- It provides a relatively high level of protection to coral trout (Figure 2).
- The inclusion of specific 'if-then' configural rules relating to lunar phase in September and December represents a more sophisticated biologically-based, cost-effective approach to protection than the status quo (Alternative 5).
- Alternative 6 is the worst alternative with respect to 'ease of enforcement'. The high costs of detecting non-compliance may need to be offset by improved deterrence through introduction of stronger penalties.
- The effectiveness of Alternative 6 as a protective measure rests on high survivorship of caught and released coral trout and assumes minimal disruption to spawning fish as a result of fishing. The post-release survivorship of coral trout and the effect of fishing on spawning behaviour would be high priorities for research should this alternative be adopted.

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Appendix 1: Workshop attendees

Participants

Tony Ayling, research scientist.

David Bateman, recreational fisher (Sunfish).

Alex Campbell, senior fisheries scientist, Primary Industries and Fisheries.

Howard Choat, School of Marine and Tropical Biology, James Cook University.

Jay Clark, AustAsia Seafood.

Peter Doherty, Australian Institute of Marine Science.

Shaun Hanson, commercial fisher (Queensland Seafood Industry Association).

Anthony Roelofs, fisheries biologist, Primary Industries and Fisheries.

Martin Russell, Great Barrier Reef Marine Park Authority.

Stephanie Slade, senior fisheries management officer, Primary Industries and Fisheries.

Bruce Stobo, charter operator.

Andrew Tobin, Fishing and Fisheries Research Centre, James Cook University.

Eric Wolanski, School of Marine and Tropical Biology, James Cook University.

Brigid Kerrigan, Manager (Fisheries Resources), Primary Industries and Fisheries (*unable to participate on the second day*).

Observers

Nicole Flint, Department of the Environment, Water, Heritage and the Arts.

Peter McGinnity, Great Barrier Reef Marine Park Authority.

Yvonne Sadovy, University of Hong Kong *(involved only in early stages of problem formulation)*.

Ian Yarroll, general manager, Harvest Management, Primary Industries and Fisheries.

Support

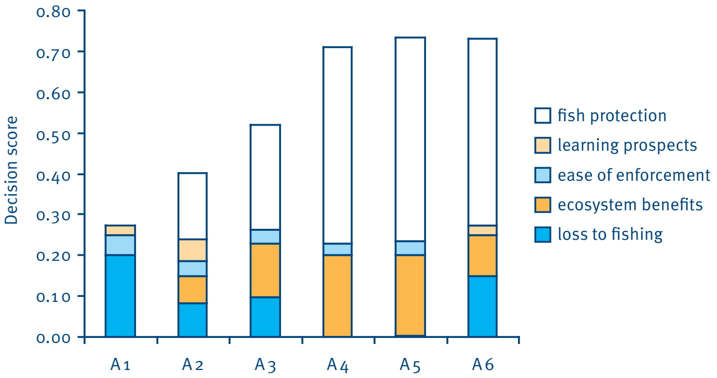
John Kung, senior fisheries management officer, Primary Industries and Fisheries.

Tracy Rout, Applied Environmental Decision Analysis, University of Melbourne.

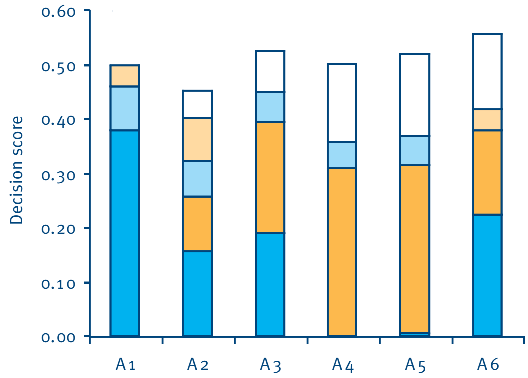
Terry Walshe, Australian Centre of Excellence for Risk Analysis, University of Melbourne.

Appendix 2: The contribution of criteria to decision scores of individual participants.

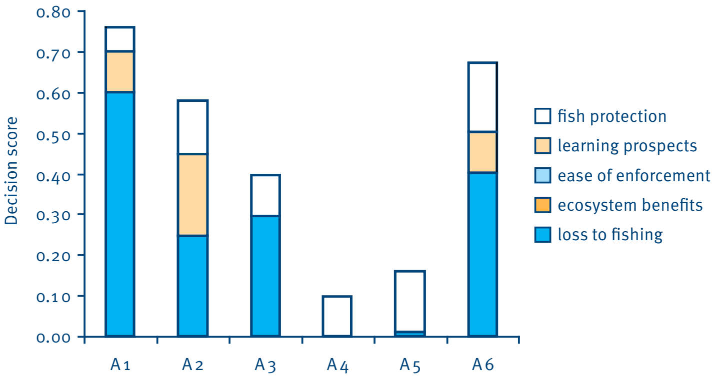
Scores refer to weights applied to the average of lower and upper bound calculations.



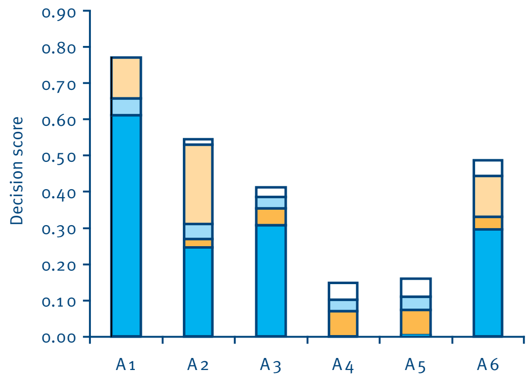
Tony Ayling, research scientist



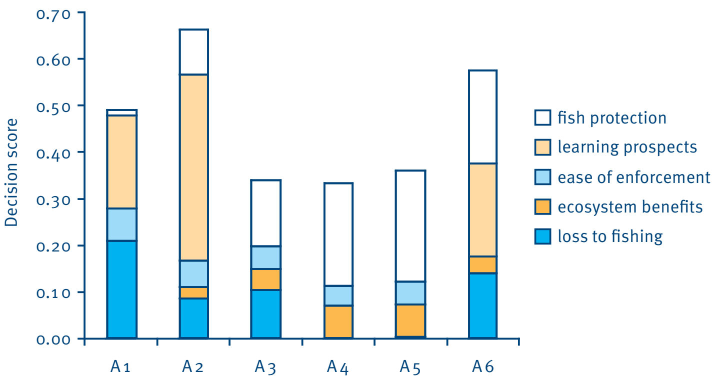
Howard Choat, School of Marine and Tropical Biology, James Cook University.



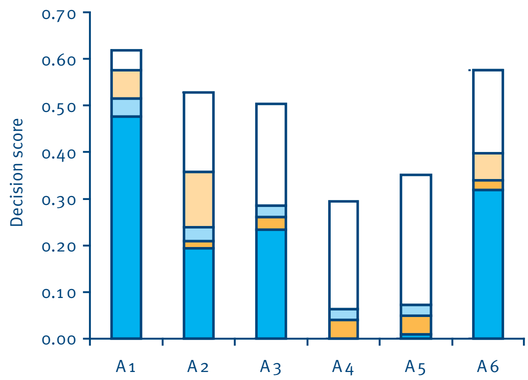
David Bateman, recreational fisher (sunfish)



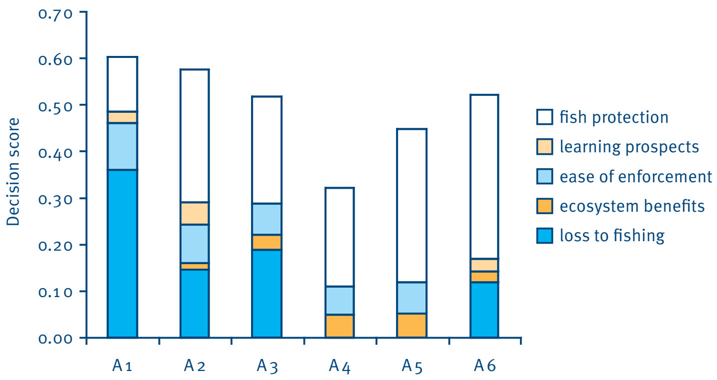
Jay Clark, AustAsia Seafood.



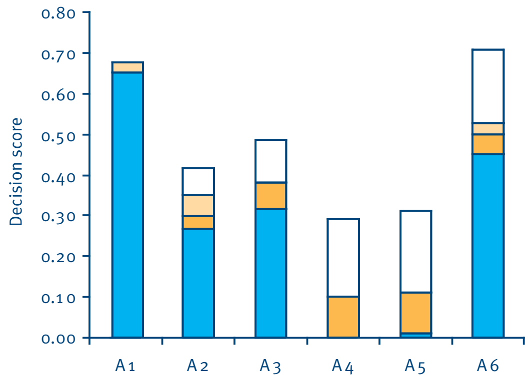
Alex Campbell, senior fisheries scientist, Queensland Primary Industries and Fisheries



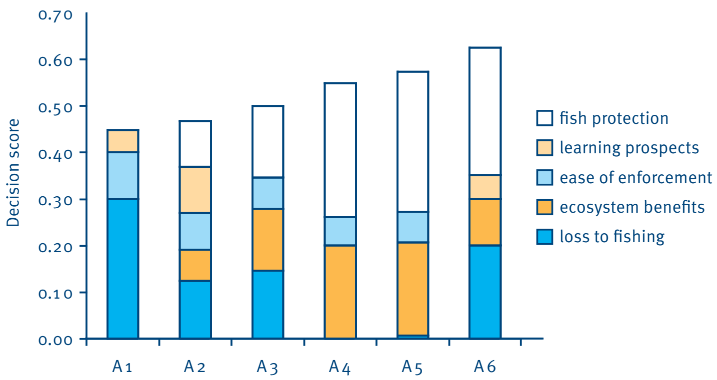
Peter Doherty, Australian Institute of Marine Science.



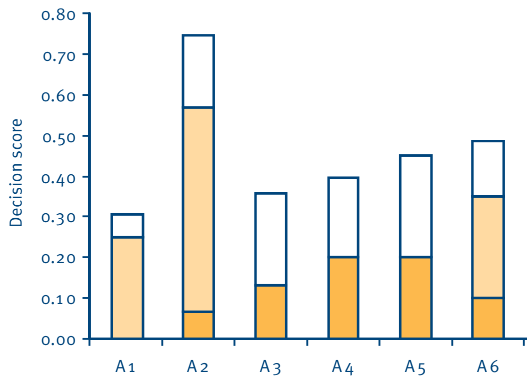
Shaun Hanson, commercial fisher
(Queensland Seafood Industry Association).



Bruce Stobo, charter operator.



Anthony Roelofs, fisheries biologist,
Queensland Primary Industries and Fisheries.



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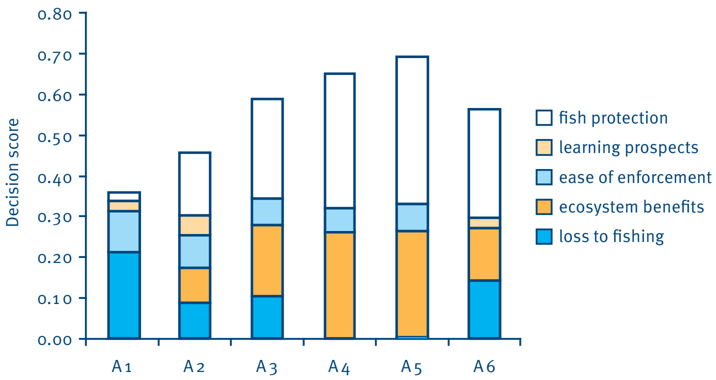
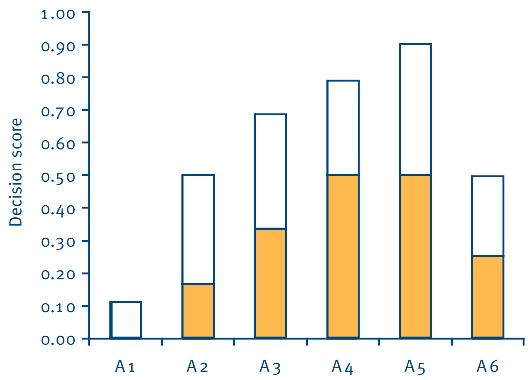
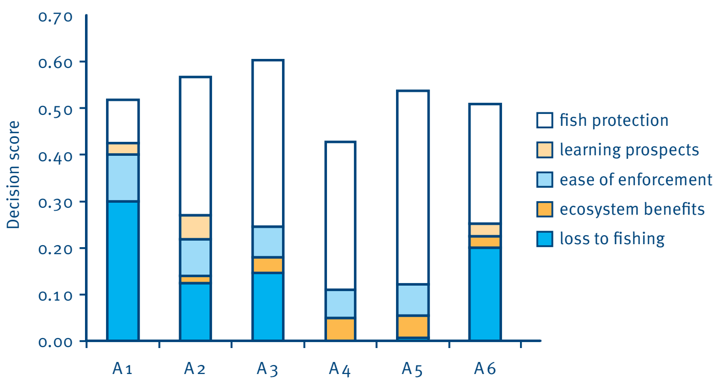


Martin Russell, Great Barrier Reef Marine Park Authority.



Eric Wolanski, School of Marine and Tropical Biology,
James Cook University.



Stephanie Slade, senior fisheries management officer,
Queensland Primary Industries and Fisheries.

Appendix 3: Key points from workshop discussions.

Throughout the workshop, participants were involved in discussions regarding the biology and spawning behaviour of key species in the coral reef fin fish fishery, the relative importance of species to each fishery sector, the merits of the alternative spawning closure regimes identified in Table 1 and research priorities identifying information that could contribute to future reviews of spawning closures. This section summarises the main points of discussion.

(i) Spawning behaviour of coral trout:

(a) Coral trout on the Great Barrier Reef (GBR) are known to form spawning aggregations; however, observed aggregations (of up to 300 fish) are not as large as spawning aggregations of other groupers in other parts of the world (e.g. Nassau grouper form aggregations of 10 000–20 000 fish in the Caribbean). The average number of coral trout on a GBR reef is approximately 2000 fish. It is not known whether fishing has impacted on the size and number of aggregations on the GBR and if so, to what extent.

(b) Coral trout on the GBR have been observed to pair-spawn; however; the relative importance of aggregation spawning and pair-spawning is unknown.

(c) Coral trout have been observed to form primary spawning aggregations and may also form secondary spawning aggregations on the same reef. It is likely that many reefs on the GBR support spawning aggregations of coral trout.

(d) As with all coral reef fin fish, recruitment of coral trout is highly variable. This variability is likely to be a major driver of coral trout abundance.

(ii) Known spawning behaviour of other coral reef fin fish:

(a) Knowledge of the spawning behaviour of coral reef fin fish species other than coral trout is significantly more limited; however, some information was presented to workshop participants showing temporal spawning behaviour.

(b) The removal of December from the spawning closure regime means that protection of those species known to spawn in December is reduced. Of significance, camouflage grouper (*Epinephelus polyphekadion*) and flowery cod (*E. fuscoguttatus*) are aggregating December spawners. These species are naturally less abundant than many other coral reef fin fish species, so constitute a lower relative proportion of the catch.

(c) Red throat emperor have been provided minimal protection under the former spawning closure regime; however, the stock assessment indicates that the stock is in good condition.

(iii) Catchability of coral reef fin fish during peak spawning periods:

(a) The effectiveness of spawning closures in protecting coral reef fin fish assumes that fish are more accessible during peak spawning times. Previous studies have not detected an increase in catchability during the months that coral trout are known to spawn on the GBR. In addition, a draft report from the Fishing and Fisheries Research Centre at James Cook University indicates that, for those species available to the fishery, there is no significant increase in the catch during October, November and December. This result from the draft report must be treated with caution however, as the analysis does not incorporate fishing effort during those months.

(iv) Species importance:

(a) Workshop participants rated coral trout as the most important species for consideration because of its role as an apex predator and its importance to fishery users, in particular the commercial fishing sector.

(b) Participants were informed that a positive relationship has been found between the abundance of coral trout on the GBR and the number of prey species.

(c) Participants were informed that outbreaks of crown of thorns starfish are less prevalent on reefs closed to fishing.

(v) Coral trout only closures:

(a) The likelihood of this strategy protecting coral trout is dependent upon the post-release survival of coral trout (it was acknowledged that coral trout would be captured and would have to be released) and the impact on spawning success in the presence of fishing activity during peak spawning times.

(b) In the case of the commercial sector, coral trout only closures may result in a reduction in fishing pressure during the closure periods as some commercial fishers are unlikely to target other species due to their low relative value.

(c) In the case of the recreational and charter fishing sectors, effort during the closure periods is likely to be relatively unaffected.

(d) Ease of enforcement is likely to be reduced under a coral trout only closure option due to fishing effort associated with other species.

(vi) Providing an exemption to spawning closures for the extended charter fishing sector:

(a) This alternative would involve identifying and exempting 'extended' charter operators from a spawning closure regime in exchange for those operators sitting out an alternative time period that would have less impact on their business operations.

(b) The charter fishing participant informed the workshop that it is likely that approximately 15 operations would qualify for such an exemption.

(c) This strategy was opposed by a number of workshop participants (predominantly those from other fishery sectors) on the grounds that it was not seen to address issues of equity.

(vi) Hydrodynamic processes:

(a) The GBR cannot be treated as a uniform system—some reefs are source reefs (for recruits) and some are sink reefs. Areas around the Swains reefs, off Bowen and off Cairns, are self-seeding.

(b) Research is currently underway to quantify the self-seeding capacity of coral trout on reefs in the Great Keppel area.

(viii) Regional management:

(a) Spawning closures to date have applied across the entire GBR in the months that coral trout are known to spawn; however, they have not taken into account the latitudinal variation in spawning.

(b) Participants from the scientific community and the commercial fishing sector noted that coral trout spawn earlier in the north (September–October) than they do on the southern GBR (November–December). This trend has been demonstrated through observations of 'ripe' fish and timing of recruitment in northern and southern reefs.

(c) A north–south split in spawning closures would be unlikely to provide additional protection to any other coral reef fin fish.

(d) Regional management may ease the impact on the marketing sector as it would result in a more continuous supply of product if, for example, the entire fishery were only closed for one month.

(e) Regional management may present some social impacts from commercial fishing boats moving between ports to avoid closure periods. There is likely to be less movement of recreational and charter fishers.

(ix) Opportunities for learning:

(a) Participants identified the following information gaps in relation to spawning of coral reef fin fish:

(i) The relationship between spawning closures (and other management arrangements including zoning) and recruitment of coral reef fin fish (i.e. what is the flow-on effect of the closures to coral reef fin fish stocks?).

(ii) Seasonal variability in spawning (both temporal and spatial variability).

(iii) Spawning behaviour: How many fish aggregate? How long do they stay at the aggregation site? How often do they aggregate? Are they more accessible to fishing during peak spawning periods? (i.e. does catchability increase?) Does fishing disrupt spawning? Are fish that are not normally available to the fishery vulnerable to capture during spawning times? Some of these questions could be answered using acoustic telemetry.

(iv) What is the relative importance of other species of coral reef fin fish in the catch of non-commercial fishers? This could be used to target further biological research for other key species.

(x) Additional comments from Professor Yvonne Sadovy:

Professor Sadovy joined the workshop for a short time during day 1 and in conversation with the fishery manager on day 2 provided the following observations:

(a) The assumption at the workshop appears to be that the other management controls currently in effect (i.e. non-spawning aggregation measures including minimum legal size, possession limits etc) are appropriate and already effective for the species. However, the quota and bag limits are not biologically based, the minimum size limit is probably too small for the species given its longevity (long-lived species should be allowed several years to reproduce to give them a reasonable chance for effective reproduction according to life history theory), and the number of spawning aggregations in the protected 33% area of the GBR is unknown. The relative importance of each management measure for protection is unknown so the spawning aggregation protection cannot be evaluated independently. Moreover, it is not clear how effective the minimum size enforcement is likely to be given recent changes undermining the ability to enforce minimum size regulation. It is not clear, therefore, that the key fishery species are sufficiently protected in the absence of spawning season closures.

(b) Due consideration should be given to the potential impact on a fishery of fishing on aggregated fishes. Possible impacts could be on social structure in the case of sex-changing species, or disturbance of the mating system that can be highly structured and form for short periods each year in relation to spawning. A precautionary approach is needed given these unknowns.

(c) High mortality of live ripe fish for the live fish trade is a problem for some traders in other countries who avoid trading gravid females that can be readily stressed.

(d) The experience with Scott and Elford reefs has shown that fished aggregations decline and that protecting spawning aggregations can lead to increased numbers in the aggregations.

(e) Given that only a few spawning site locations are actually known and also given that it is possible that not all coral trout spawn in aggregations, the most effective way to protect reproductively active/spawning fish is by seasonal protection. This also means that it is not necessary to know the locations of spawning aggregations.

(f) Adaptive management would suggest that any changes to the current management regime should be gradual and the outcomes monitored and assessed over several years before further changes to management are made. Given that last year 2 × 9-day closures replaced 3 × 9-day closures, this change should be monitored for several years with all else staying the same to evaluate the possible outcomes of the shift in closure regime.

(g) Loss of December protection (last year) has substantially reduced protection for two Epinephelus species. This could be an issue in future if pressure to exploit them increases; this is a possibility from the live reef fish sector since these species are among the most important in the fishery. We know that such aggregations in other countries have been rapidly overfished for live fish.

Appendix 4: Background materials provided to participants prior to the workshop.

Coral reef fin fish spawning closures

Risk assessment workshop

12 – 13 May 2009
9am – 5pm
Russell 1 & 2
Berkley's On Ann
Rendezvous Hotel Brisbane
255 Ann Street, Brisbane

THE UNIVERSITY OF MELBOURNE

Queensland Government

Background

This workshop will explore candidate alternatives for spawning closures to be applied 2009 – 2013.

The *Fisheries (Coral Reef Fin Fish) Management Plan 2003* introduced three nine-day spawning closures for coral reef fin fish on the Great Barrier Reef (GBR). The closures applied to the new moon periods in October, November and December for the years 2004-2008. On the basis of advice regarding the biological effectiveness of the December closure and the high costs to fishers the December closure was removed in 2008.

The 2004 – 2008 closures were designed to provide protection to the key commercial target species, coral trout. The peak spawning periods of coral trout are reasonably well known. While critical to the commercial sector, coral trout is of lesser importance to recreational and charter-based fishing. A relative lack of information on the spawning habits of other species has lead to a tendency to place lesser emphasis on their consideration. A more comprehensive assessment could consider:

a. Coral trout (*Plectropomus* spp. & *Variola* spp.)

b. Red throat emperor (*Lethrinus miniatus*)

c. Red emperor (*Lutjanus sebae*)

d. Large mouth nannygai (*Lutjanus malabaricus*)

e. Spangled emperor (*Lethrinus nebulosus*)

f. Camouflage grouper (*Epinephelus polyphekadion*)

g. Flowery cod (*Epinephelus fuscoguttatus*)

h. Greasy rockcod (*Epinephelus tauvina*)

i. Spanish flag (stripey; *Lutjanus carponotatus*)

j. Tuskfish (*Choerodon* spp.)

Closures targeting coral trout afford some protection to other coral reef fin fish species, although the magnitude of this effect is speculative. The imperative to explicitly consider other species rests on judgments concerning

- the importance of each species to each sector,
- the importance of each sector, and
- the capacity of existing controls other than spawning closures to provide adequate protection.

These judgments are a central theme of the workshop.

An initial task for the workshop is identification of candidate alternatives. Any closure regime implemented beyond 2008 needs to provide adequate protection for spawning coral reef fin fish species, within a constraint that the impost on commercial and recreational (including charter) fishing is no greater than for the period 2004 – 2008. ReefMAC has recommended a five year package comprising two years (2009-2010) of no spawning closures followed by three years (2011-2013) of two nine-day spawning closures (around the October and November new moons of each year; six days prior to the new moon and two days following the new moon).

Other alternatives may include elements that address

- Different timing of closures (moon phase, month and duration).
- Species-specific closures.
- Exemptions for specific sectors (e.g. the extended charter fleet).

The focus of the workshop is assessment of the merit of alternative *spawning closure regimes* in terms of their capacity to provide *adequate protection* to the *fishery*. It does *not* seek to directly address broader socio-economic issues, conservation-dependent species (or communities), or changes to other management controls (e.g. allowable catch, bag limits etc.).

2 Identified from the Ecological Risk Assessment of the Other Species component of the Coral Reef Fin Fish Fishery, 'species of special interest' from the Workshop Summary: Management and Science of Fish Spawning Aggregations in the GBRMP July 2007, or target coral reef fin fish species from conditions of filleting permits issued by the DPI&F.

Objectives

- Identify a shortlist of candidate alternatives for spawning closure regimes.
- Characterise uncertainty in the merit of alternatives.
- Provide advice on an appropriate closure regime for the period 2009 – 2013.

Preparatory readings

Extract from: Tobin, R.C., Simpfendorfer, C.A., Sutton, S.G., Goldman, B., Muldoon, G., Williams, A.J., Ledee, E. (unpubl.). *A review of the spawning closures in the Coral Reef Fin Fish Fishery Management plan 2003*. **Draft Report** to the Queensland Department of Primary Industries and Fisheries. February, 2009. Fishing and Fisheries Research Centre, School of Earth and Environmental Sciences, James Cook University.

Extract from Anon. (2009). *Annual status report 2008. Coral Reef Fin Fish Fishery*. The State of Queensland, Department of Employment, Economic Development and Innovation.

Agenda

Berkley's On Ann, Rendezvous Hotel Brisbane
255 Ann Street, Brisbane

Time	DAY 1 – Tuesday 12 May
9.00	Problem formulation 1: key species and candidate spawning closures
10.30	Morning tea
10.50	Problem formulation 2: an endpoint for 'adequate protection'
12.00	Assessment of alternatives for two species
12.30	Lunch
1.20	Assessment of alternatives for all species
3.00	Afternoon tea
3.20	Cross-examination of perspectives
4.15	Identifying key trade-offs and uncertainties
5.00	Close
6.30	Evening dinner (optional)

Time	DAY 2 – Wednesday 13 May
9.00	Confronting trade-offs: weighing the importance of fish species
10.30	Morning tea
10.50	Discussion of outcomes issues overlooked contrasts in perspectives insights for monitoring and research implications for decision-making
12.30	Lunch
1.20	Exploring localised effects
3.00	Afternoon tea
3.20	Risk ranking
4.00	Report and discussion of outcomes
5.00	Close

Extract from: Tobin, R.C. *et al.* (unpubl.). ***A review of the spawning closures in the Coral Reef Fin Fish Fishery Management plan 2003.*** **Draft Report to the Queensland Department of Primary Industries and Fisheries. February, 2009. Fishing and Fisheries Research Centre, School of Earth and Environmental Sciences, James Cook University.**

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Summary

The review of biological information relevant to the consideration of the current spawning closure regime in place for the Queensland Coral Reef Fin Fish Fishery (CRFFF) utilised both published information and unpublished data from the Effects of Line Fishing Project. The analysis showed:

The previous three 9-day spawning closures over the new moon periods of October, November and December provide some protection for spawning individuals of a range of species in the fishery.

The main exception to this is the red throat emperor, which spawns during winter and spring.

An analysis combining information on the readiness to spawn and the importance in the commercial catch demonstrated that there are significant differences in the effectiveness of closures for the protection of spawning stocks, with October being the month that had the highest potential to protect spawning commercial stocks of coral reef fish. A similar analysis could not be completed for the recreational sector because of a lack of detailed catch data.

None of the currently fished CRFF species showed substantially higher levels of catch during spawning months than during non-spawning months.

Limited data was available on the timing of spawning relative to moon phase. The available published data demonstrates that there is considerable variation in the timing of spawning relative to moon phase. Some species spawn mostly around new moon periods (e.g. coral trout), while other species spawn on full moons and others show no lunar periodicity.

Seasonal (monthly) patterns in reproductive activity

Published studies provided information on the reproductive biology of 18 species of fish from the GBR. This included three species that are not recorded as having been taken in the CRFFF and two that are currently protected by legislation. There was considerable variation in both the length and timing of spawning season among species (Figure 1). Generally, the majority of species spawn in the spring and summer months. One species was reported to spawn all year (*Parapercis cylindrica*) while some, notably *Lethrinus miniatus* and *L. nebulosus* are winter-spring breeders. For all exploited species except *L. nebulosus*, at least one month of spawning occurs within the months of the previous spawning closures. The spring-summer spawning season for *P. leopardus* is further confirmed by work of Light and Jones (1997) who found larval recruits from October through February.

Lunar patterns

The few studies published on GBR fishes are summarised in Table 1. There are many species which spawn throughout the lunar month; some, particularly the serranids, spawn predominantly around new moon, and a minority follow semi-lunar activity. The data are too few, however, to enable the formulation of any generalisations at this stage.

Coral trout are well documented as spawning around the new moon period, but there is no published information on the lunar timing of the spawning of other key target species such as *Lutjanus miniatus, L. sebae, L. malabaricus* and *L. erythropterus*. Kritzer (2004) demonstrated *Lutjanus carponotatus* spawns around the new moon similar to coral trout. It is possible that some fishes in the GBR CRFFF do not spawn monthly, as *Lutjanus vittus* from the North West Shelf of Australia follows a semi-lunar pattern of spawning 3 days after new moon and 6 days after full moon (Davis and West 1993).

Proportion of catch taken during spawning months

The proportion of the commercial catch taken during spawning months was determined for 14 species, including 4 protected species (Figure 3). Only one species, Maori wrasse (*Cheilinus undulatas*), showed a proportion of catch much greater than 0.0833, suggesting that prior to their protection that they were mostly caught during spawning months. Three important commercial species - common coral trout (*Plectropomus leopardus*), red throat emperor (*Lethrinus miniatus*) and flowery cod (*Epinephelus fuscoguttatus*) - had values that suggested that slightly greater proportions of catch were taken during spawning periods. All other species had catch proportions below 0.0833, indicating that proportionally more catch was taken during non-spawning months.

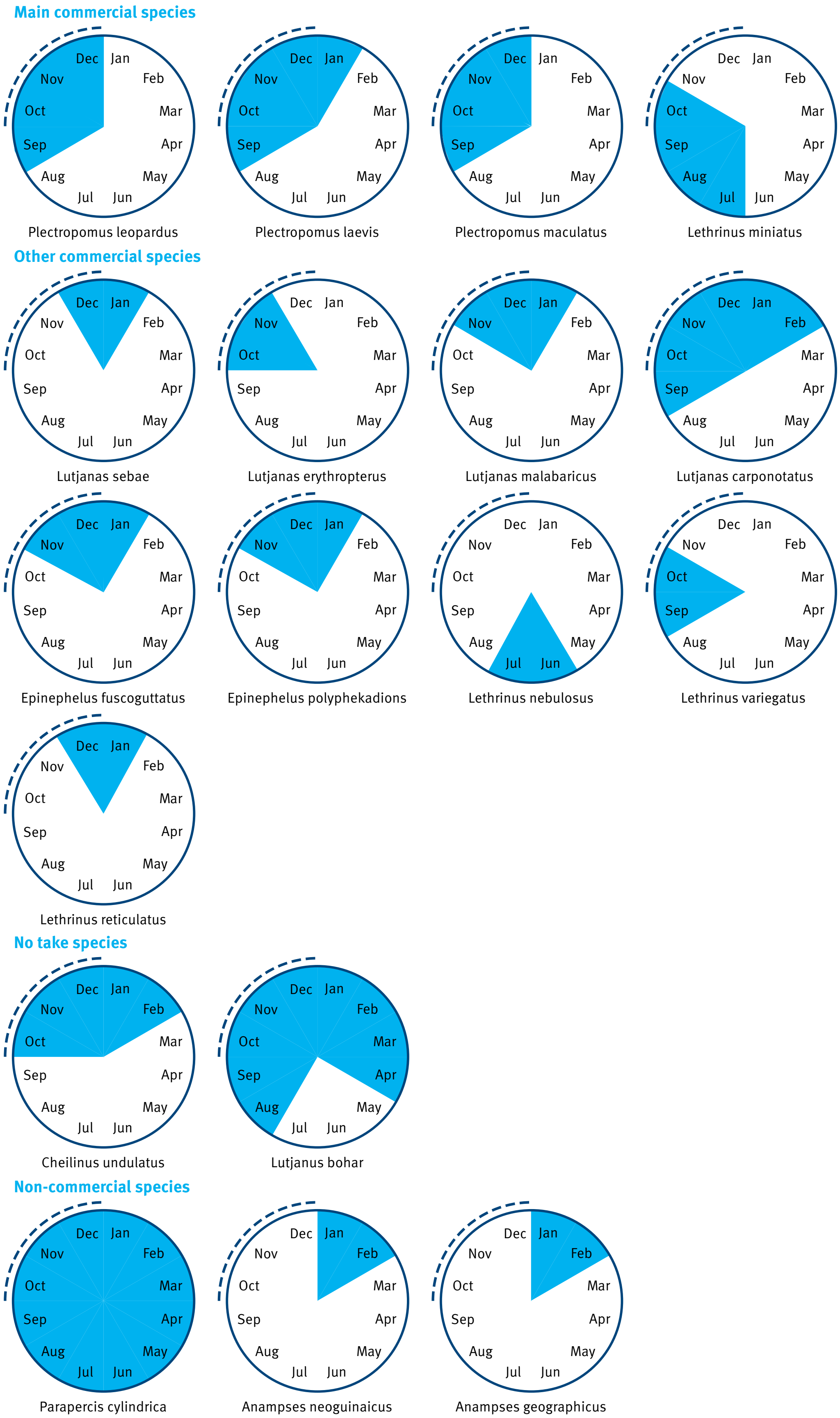

Figure 1. Reproductive seasons of commercial reef fish spawning on the GBR derived from literature. Grey regions indicate months in which significant reproductive activity has been recorded. The dotted line indicates the months in which there are currently 9-day closures to fishing.

Discussion

Monthly patterns of spawning activity

The information reported in this review provides a broad view of the reproductive biology and spawning activity of economically important coral reef fish species that occur within the waters of the Great Barrier Reef. The results of the analysis of the timing of spawning activities demonstrated that the majority of species taken by commercial and recreational fishers do so during at least one of the months of the current three 9-day closures during the new moon periods of October, November and December. There were few reports of spawning in these species between February and August (inclusive). The one exception to this was the red throat emperor which spawned during winter months. These data suggest that the timing of the current closures protect at least some spawning activity of the majority of coral reef fish species on the GBR.

The timing of the spawning in the key coral reef fish species on the GBR is also likely to be a function of latitude due to water temperature effects (Claydon 2004). Evidence for possible regional differences in the timing of spawning comes from several species of emperor that follow different patterns in Noumea than they do on the GBR and may respond to water temperature rather than time of year (Church 1995; Loubens 1980; Sheaves 2006; Williams et al. 2006). It should also be noted that changes in water temperatures associated with climate change could effect the timing of spawning activities, however, insufficient data are currently available to predict what these changes may be, or if they will occur.

It is known that the species composition of the recreational sector is substantially different from that of the commercial sector. Common coral trout is much less important in the recreational sector, while emperors and "reds" (*Lutjanus sebae, L. malabaricus* and *L. erythropterus*) are much more commonly taken (Simpfendorfer et al 2007). This difference in the species composition means that the effectiveness of the timing of closures for the recreational sector may be different than for the commercial sector.

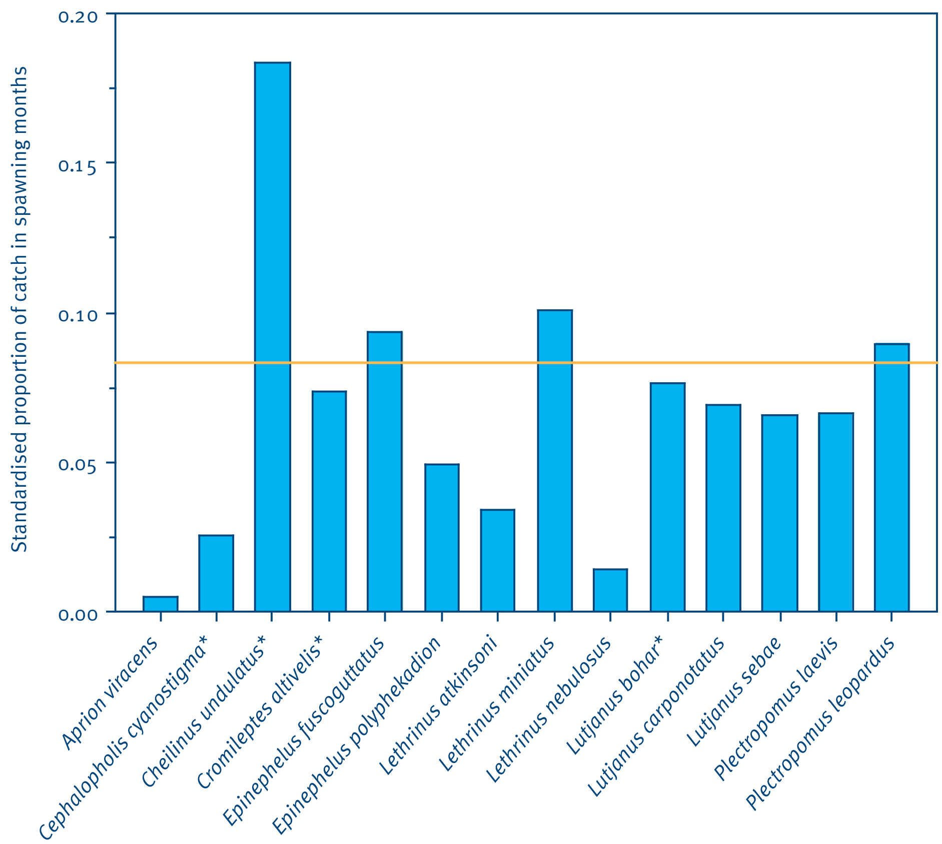

Figure 3. Proportion of the commercial catch taken in spawning months for major species in the CRFFF. Current no-take species are indicated by astrices. Reference line indicates the point at which equal proportions of catch would be taken in all months. Species above the line indicate those in which more catch was taken in spawning months than in non-spawning months. Based on QDPI&F CFISH data from 1998 to 2004. No-take species included those protected by legislation and those that do not reach the 38 cm minimum size length for serranids.

Table 1. Published records of reef fish spawning relative to lunar phase in Great Barrier Reef waters.

Family and species	Lunar stage	Lunar days	Location	Reference	Data
Lutjanidae					
Lutjanus carponotatus	New Moon	1	GBR	Kritzer J P, 2004	Field and laboratory studies
Lutjanus erythropterus	Distributed throughout full lunar cycle		Innisfail to Cooktown	McPherson G R et al., 1992	Fishery data
Lutjanus malabaricus	Distributed throughout full lunar cycle		Innisfail to Cooktown	McPherson G R et al., 1992	Fishery data
Lutjanus sebae	Distributed throughout full lunar cycle		Innisfail to Cooktown	McPherson G R et al., 1992	Fishery data
Pinguipedidae					
Parapercis cylindrica	bi-monthly at new and full moon		from Lizard Is to One Tree Island	Walker , 2007	Field and laboratory work
Pomacentridae					
Pomacentrus wardi	1st and 3rd quarter		One Tree Island	Doherty P, 1983	Field work
	1st and 3rd quarter		One Tree Island	Doherty P, 1983	Field work
Serranidae					
Epinephelus fuscoguttatus	may spawn throughout much of the lunar cycle	16 27	GBR	Pears R J et al., 2007	Field and lab (histological) work
Epinephelus	may occur throughout much of the lunar cycle		GBR	Pears R J et al., 2007	Field and lab (histological) work
Plectropomus leopardus	New Moon		off Townsville	Frisch A I et.al. , 2007	Field and laboratory work
	New Moon	1	Scott Reef	Samoilys M A and L C Squire, 1994	Field and laboratory work
	New Moon	1	Lizard Island	Zeller DC, 1998	Field observations
	New Moon	1	Lizard Is to Townville	Brown I W et al., 1994	Field and laboratory work
	New Moon	27 2	Orpheus Island, Hayman, Keppel etc.	Frisch A I and L van Herwerden, 2006	Field and laboratory work
	New Moon, flooding tide	29 5	Scott & Elford Reefs	Samoilys M A, 1997	Field and laboratory studies
Plectropomus maculatus	New Moon	27 2	Orpheus Island, Hayman, Keppel etc.	Frisch A I and L van Herwerden, 2006	Field and laboratory work
Tetraodontidae					
Canthigaster valentini	all phases		Lizard Island	Gladstone W, 1987	Field work
	no lunar cycle		Lizard Island	Gladstone W and M Westoby, 1988	Field work

For example, “reds” are reported to more commonly spawn during the summer, and so greater protection of the spawning of species important to the recreational sector may be achieved during this period. However, until detailed catch data are available for the recreational sector it will be difficult to determine the most appropriate timing for closures to protect recreationally important coral reef fish species on the GBR.

One of the assumptions required for the use of spawning closures is that spawning fish are more vulnerable during these periods. Previous studies on the GBR have not been able to demonstrate that the main commercial species have a significantly higher catchability during spawning periods. Mapstone et al (2001) could not find evidence for increased catch rates during spawning periods of common coral trout, but did find some evidence that red throat emperor catch rates were elevated during spawning months. The analysis of the proportion of catch taken during spawning months in this review only identified the Maori wrasse as having a substantially larger proportion of the catch taken during spawning periods. Since this species is currently protected by legislation, spawning closures will not provide any further protection. The analysis also identified slightly greater proportions of catch taken during spawning months in three other species. Since these data do not take account of differences in fishing effort between months these results should be interpreted with caution.

Lunar timing of spawning

Lunar synchronisation in reef fish spawning behaviour is well know and documented for many species throughout the Indo-Pacific and Caribbean regions (Hamilton et al. 2004; Johannes 1981; Colin et al. 2003). From the reviews of Russell (2001) and Claydon (2004) we know that spawning in many GBR fish species is also related to lunar phase.

However, while coral trout spawn primarily around the new moon, this timing is not universal amongst other CRFF species and is likely to vary among species. For most CRFF species, lunar patterns are not well defined and there are too few data to generalise or make predictions as to the lunar timing of their peak in reproductive activity. Some very preliminary generalisations can be made – coral trout and many other species indicate a preference to spawn on new moons, although spawning behaviour has been documented during the full moon phase for common coral trout (Samoilys 1997). We also know that the time of spawning does not follow predictable patterns within taxonomic groupings – some members of a family may spawn on new moon, others on full moon, while others may spawn throughout the month. Within the lutjanids for example, *Lutjanus carponotatus* spawns over new moon, *L. cyanopterus* and *L. jocu* spawn over full moon, and *L. erythropterus, L. malabaricus* and *L. sebae* spawn throughout the lunar cycle (Heyman et al. 2005; Krajewski and Bonaldo 2005; McPherson et.al. 1992).

The timing of the current spawning closures over new moon periods therefore provides variable protection to spawning activities within the months that they occur. Species that spawn mostly on new moons (e.g. common coral trout) will receive better protection than those that do not. However, further research will be required to fully understand the timing of spawning relative to moon phase for coral reef fish species on the GBR and hence evaluate the timing of the current closure regime.

Conclusions

The current review of biological information suggests that the previous three 9-day closures protect at least some spawning of the majority of important coral reef fish on the GBR. Detailed analysis suggests, at least for the commercial sector, that there is variability in the effectiveness of these closures because of differences in spawning intensity between months. However, without more specific and detailed biological knowledge, it is currently difficult to assess exactly how effective the current spawning closures are in providing protection to reef fishes from over-exploitation throughout the entire GBR or for all sectors of the fishery. Significant information gaps exist, and should be addressed via targeting sampling of CRFF species within and outside of the assumed current spawning times along the length of the GBR to enable a more detailed understanding of timing of spawning. Further investigation is also needed into the occurrence of spawning aggregations, their size and distribution, as well as the response of spawning fish to fishing at the time of spawning. Further, research into movement of CRFF species into and out of green zones during spawning times would help determine the level of protection afforded these species by the GBR Zoning Plan. Regardless of these information gaps, the effectiveness assessment presented here provides a mechanism for managers to assess the relative impact that alternative spawning closures are likely to have in different months of the year. This will be particularly useful in a revision of the current closures. Any changes in spawning closures will need to consider the socio-economic impacts of such management changes.

Extracts from: Anon. (2009). *Annual status report 2008. Coral Reef Fin Fish Fishery.* The State of Queensland, Department of Employment, Economic Development and Innovation.

The following information has been updated following the workshop. The updated annual status report can be found at http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/28_14043_ENA_HTML.htm

Fishery profile 2007–08

Total harvest from all sectors: Approximately 4862 t[1]

Commercial harvest: Approximately 1807 t

Recreational harvest (2005): Approximately 2601 t

Indigenous harvest (2000–01): Approximately 108 t

Charter harvest: 346 t

Commercial Gross Value of Production (GVP): Approximately $40 million

Number of licences: 368 RQ fishing endorsements across the L1, L2, L3 & L8 fisheries[2]. 395 charter licences.

Commercial boats accessing the fishery: 237 primary vessels. Approximately 218 charter boats.

Fishery season: Coral reef fin fish are caught all year round. There are three 9-day closures that occur between October and December each year[3].

Source: Commercial Fisheries Information System (CFISH) database, 10 November 2008.

Table 2: Percentage of quota used for CT, RTE and OS in the 2007–08 financial year.

	Allocated quota	Quota minus DEWHA holdings	Total catch	% of available quota used
CT	1 423 982	1 288 158	1 158 107	90
RTE	693 630	618 986	233 227	38
OS	1 065 339	956 538	419 086	44

Source: Quota monitoring unit, 19 Dec 2008

1 For the purpose of this report, the total harvest estimate for 2007–08 includes the recreational harvest estimate from 2005, based on the assumption that the subsequent years of catch would be similar.

2 During the period Feb 06 – Dec 07 all L6 and L7 endorsements were replaced with L1 fishery symbols.

3 The spawning closure for December 2008 was removed

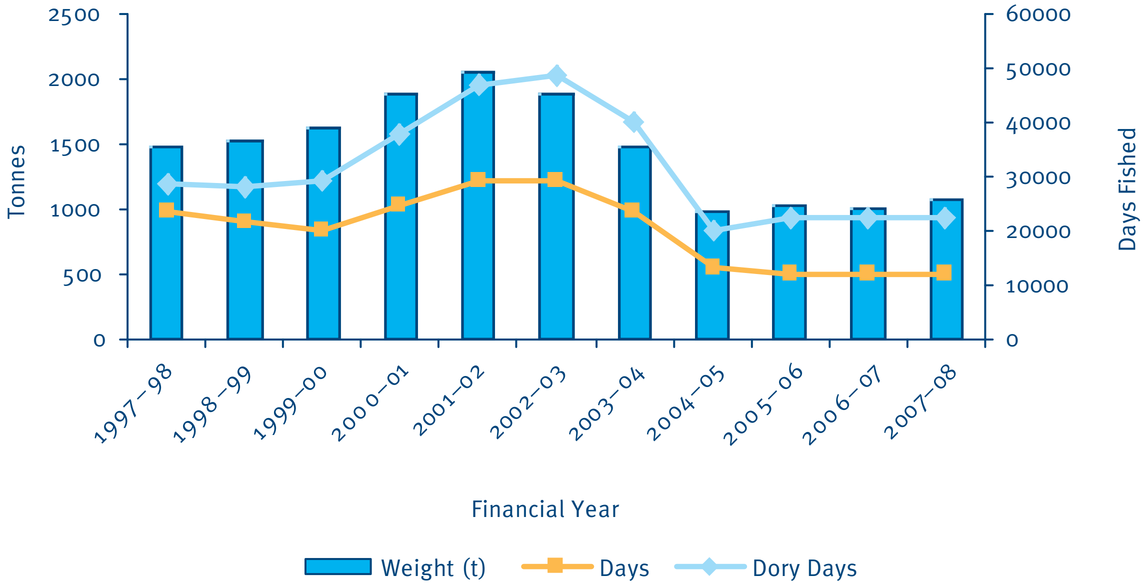

Figure 2: Total commercial catch and effort (days and dory days) of coral trout by quota year 1997-2008.

Source: CFISH database, 12 December 2008

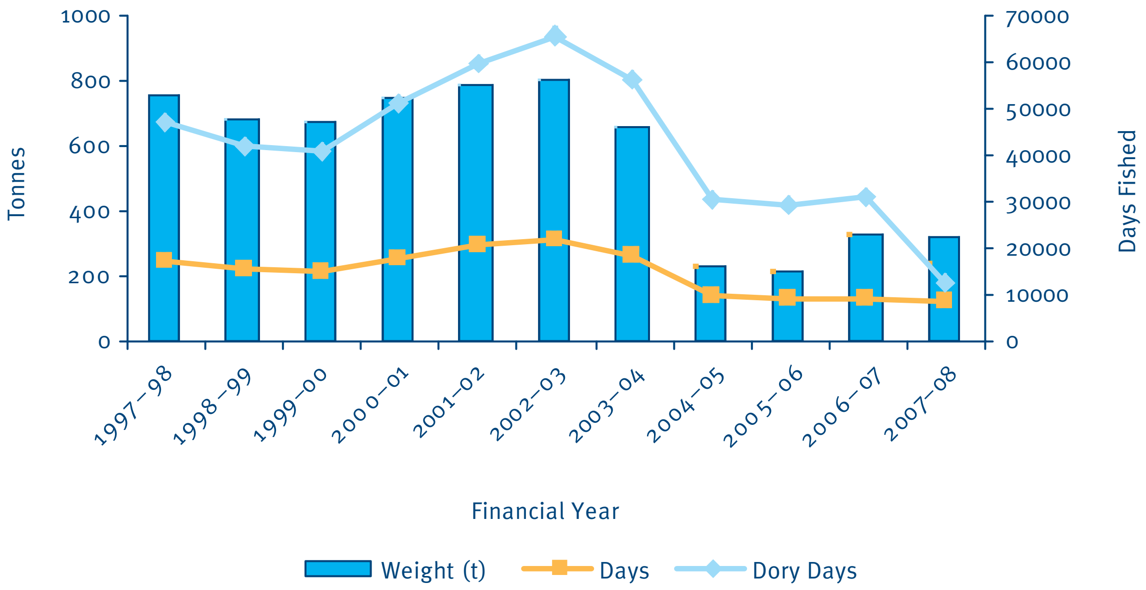

Figure 3: Total commercial catch and effort (days and dory days) of red throat emperor by quota year 1997–08.

Source: CFISH database, 12 December 2008.

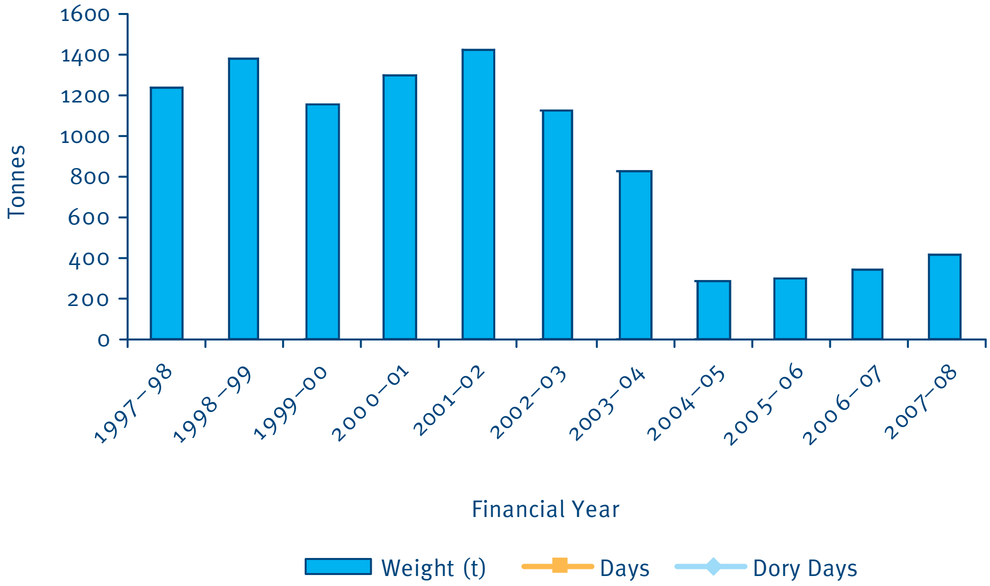

Figure 4: Total commercial catch of other species by quota year 1997-2008.

Source: CFISH database, 12 December 2008

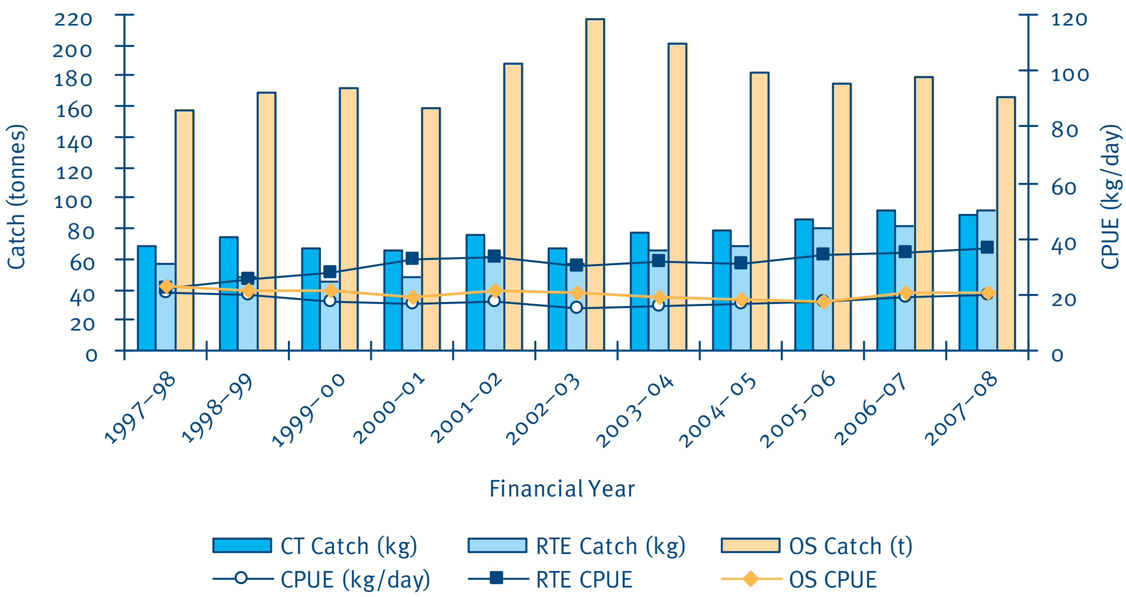

Figure 5: Charter catch of CT, RTE and OS species as reported in logbooks by financial year, 1997–98 to 2007–08.

Source: CFISH database, 12 December 2008.