Ecosystem Based Management: Linked-ecosystem modelling of the Great Barrier Reef

Dr. Neil A Gribble
QDPI&F, Sustainable fisheries, Northern Fisheries Centre, Cairns.
PO Box 5396 Cairns 4870.

Key words*: ECOPATH, linked-ecosystems, Ecosystem based management (EBM).*

EXTENDED ABSTRACT

In the current study the basic GBR prawn-trawl ECOPATH trophic model was expanded into a spatially explicit "linked-ecosystem" GBR ecosystem model, looking at the biodiversity and flows within and between the component: mangrove, lagoon-seagrass, and coral reef systems. The particular application of the model was to identify the impacts of the major fisheries in each of these systems, and the possible confounding interaction of separate spatial and fishing-effort management plans. The scope of the model was further enhanced by the addition of recent comprehensive survey data from the length of the GBR World Heritage Area, allowing large scale spatial simulations to be carried out.

Up till now there has been no way to determine the cumulative ecosystem effects of separate State and Commonwealth management initiatives nor to identify synergies or antagonisms between Commonwealth spatial zoning and the multiple State fisheries management plans. In this context the addition of spatially explicit habitat data to the equilibrium GBR model significantly buffered the predicted volatility in trophic guild biomass within the ecosystem, by providing both explicit and *de facto* spatial refugia from fishing pressure. The simulations showed that explicit protected "no take" zones, such as initiated by the Commonwealth, must be of adequate size to allow for "edge effects" caused by illegal fishing; particularly if sited in remote areas. Fishing tended to concentrate on the borders of the "no take" zone, which produced "gauntlet" effects to the movement of some groups.

Vulnerable species did better within "no take" MPA areas, but scavenger/opportunistic species did worse. In the context of policy formulation, we discuss how fisheries policy development by State and Commonwealth management agencies may contribute to better defining and implementing Ecosystem Based Management (EBM). Such policies must take account of the Australia-wide initiatives, to (i) adopt an EBM approach to fisheries management, enforced through the Environment Protection and Biodiversity Conservation Act (1999), and (ii) implementation of a national representative system of MPAs and upgrade the protective zoning within established MPAs.

Introduction.

The Australian Great Barrier Reef Marine Park (GBRMP) covers 325,848 sq km of tropical reef, islands, inter-reef areas and lagoon environments and is a designated “multi-use” World Heritage Area. By its charter the Great Barrier Reef Marine Park Authority (GBRMPA), must balance the needs of indigenous traditional owners, the existing commercial and recreational fishing interests, and the conservation requirements of the park's world heritage area status (Gribble 2005a). Management of fishing, in all its forms, is seen as a major challenge as the harvest, bycatch and collateral damage due to large-scale fisheries are likely to have the greatest anthropogenic impacts on the highly complex and diverse ecosystem of the park (Gribble and Robertson, 1998).

As of January 2007, a fleet of up to 430 commercial prawn trawlers were licensed to operate within the GBRMP World Heritage Area, as were potentially 1,400 inshore gillnet licences (≈ 300 boats), 200 line and over 1,000 pot licences (≈ 300-400 fishers). On average 330 trawler operators and 641 other commercial fishers derive a large proportion of annual income from the GBR World Heritage Area (Lew Williams, QDPI&F Senior Fisheries Economist, pers com. 2005).

Recreational fishers tend to be concentrated around the major population centres but the charter-boat fishing industry can extend the recreational harvest over the entire GBR. A combination of local and tourist sectors exceeds 10,000 recreational fishers annually (Jim Higgs QDPI&F Fisheries pers com. 2005). The GBRMP was designated as a "multi-use" World Heritage Area, which means these fisheries must be accommodated but that their activities must also conform to the conservation obligations of a designated World Heritage Area.

Current management of fishing activity within the GBRMP is two-tiered involving both Commonwealth and State agencies. The Commonwealth GBRMPA controls usage within the park via broad spatial zoning; ranging from general purpose (Open or Blue zones) to fully protected no-take (Closed or Green zones). This zoning is imposed over the top of regulatory Fisheries Management Plans, which are the responsibility of the state via the Queensland Department of Primary Industries and Fisheries (QDPI&F). Neither GBRMPA zoning nor State legislation cover indigenous fishing, so long as the harvest is for traditional use and not for commercial purposes.

Under both Commonwealth and State legislation, as well as through international obligations of the World Heritage Area listing, management of the GBR is committed to the ecologically sustainable development of fisheries, and most importantly, conservation of their supporting ecosystems.

Management plans, however, are currently formulated as stand-alone initiatives that concentrate on the sustainable harvest of target species, having little regard for other fisheries that may be directly affected or for indirect ecosystem effects. Similarly the zoning of the Commonwealth controlled Marine Park is primarily for biodiversity conservation, not optimised for fisheries management, and has been the subject of legal conflict and compensation claims.

From a biological rather than legal perspective, there has been no way to determine the cumulative ecosystem effects of these separate management initiatives nor to identify synergies or antagonisms between them.

In response, the Gribble (2000) trophic mass-balance ecosystem model has been expanded into a "linked-ecosystems" model (see also Gribble 2005a, 2005b), looking at the biodiversity and biomass flows within and between mangrove, lagoon-seagrass, and coral reef systems. The particular application of the expanded model was to identify the effects of the major fisheries in these systems, and the possible confounding effects of the Commonwealth spatial zoning changes and individual fisheries management plans legislated by the State.

Methods.

(i) Main characteristics of the ECOPATH model

The ecosystem simulations of the Great Barrier Reef World Heritage Area were implemented by means of ECOPATH EwE (version 5 beta) software (Christensen et al 2000) using the ECOSIM and ECOSPACE routines for temporal and spatial simulations respectively (Christensen et al., 2000) More detail on the structure and underlying equations of ECOPATH, and of the base "GBR-prawn" and "GBR Linked Ecosystem" models, are presented on the ECOPATH website www.ecopath.org, in Christensen et al (2000), and Gribble (2000, 2003, 2005b) respectively.

(ii) Trophic structure of the GBR linked ecosystem model.

The base ecosystem model is an equilibrium trophic hierarchy, with the biomass flows balanced such that there are not more predators than prey to feed them, nor conversely are there "wasted" prey with insufficient predators to exploit the resource (see also Christensen et al (2000),. There are 32 trophic guilds, including 25 from the original "GBRprawn" model (Gribble, 2000, 2003), plus inshore finfish species groupings and juvenile life-history stages (Figure 1). The linkage of the component habitat predator-prey systems is via:

- Linked "pools" of inshore juveniles and offshore adults of the same species
- Diet of each component depends on other guilds within that habitat, effectively separating the habitats to a large degree; eg, reef species feed mainly on other reef species.

ECOSIM and ECOSPACE simulations allow preferred habitats to be allocated for each guild, with some overlap provided. Pelagic trophic guilds such as "sharks and rays" can feed across all component systems providing food chain linkages (see Figure 1).

Only a simplification of the full mangrove forest/swamp ecosystem, along with the coastal gillnet fishery, was included in the current linked ecosystem model. As with all models the aim was to capture the major biomass dynamics and flows of the much more complex, "real" system.

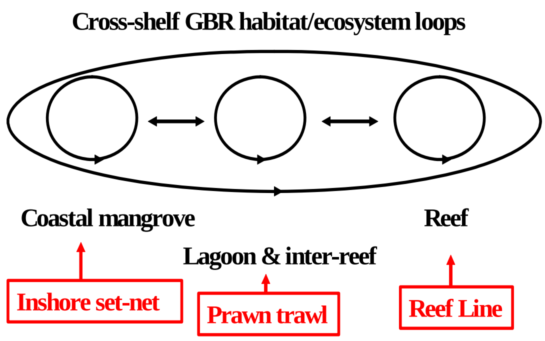


Figure 1. Linked ecosystem model of the Great Barrier Reef World Heritage Area cross-shelf (from (Gribble 2005 a & b). Boxes indicate the fishery that impacts a particular habitat/ecosystem; loops indicate the linkage of habitat/ecosystems to the greater reef-wide ecosystem.

(iii) Spatial simulations and speed of movement.

The "GBR linked ecosystem" model was made spatially explicit by mapping five broad habitat types, (fringing mangrove swamp, inner reef lagoon, mid-shelf reef/shoals, mid-shelf inter-reef, and outer reef lagoon, see Figure 2) onto a virtual landscape and moving the trophic guilds across them. Movement rates were set at biologically reasonable speeds for typical species within each guild. Closures or spatial zoning can then be overlaid on this spatially explicit "virtual" system of habitats (see Figure 2), with the associated linked-ecosystems, to determine potential impacts of various management scenarios.

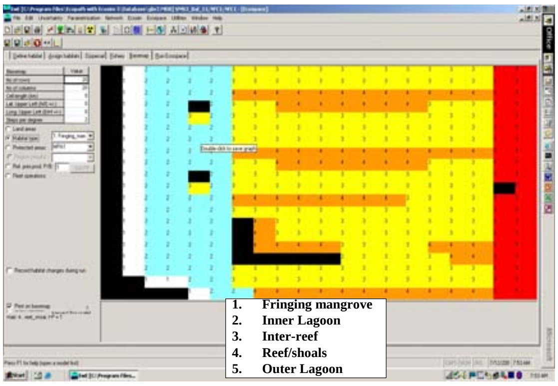


Figure 2. Map (virtual) of the Great Barrier Reef World Heritage Area cross-shelf. (taken from the input screen of the ECOPATH EwE, ECOSPACE simulation).

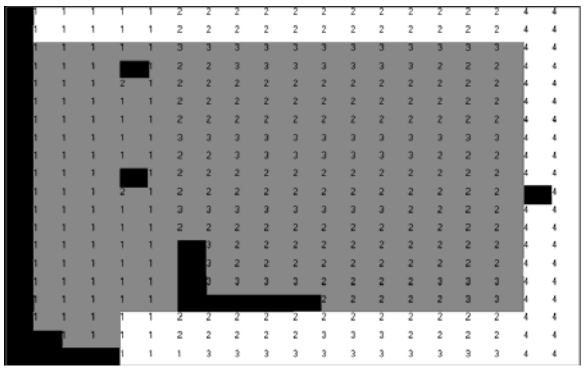
Simulations:

(See also Gribble 2005b). For the purpose of the current study the model's fishery component was divided into two fleets: (i) the reef line fishery for large reef and inter-reef carnivores (schooling and non-schooling), combined with indigenous harvest of turtles; and (ii) the prawn trawl fishery for paeneid prawns, which produces a high proportion of discarded bycatch, mainly small fish. For the model, the cost of fishing was increased particularly in areas further offshore which are more costly to access, and present a risk of loss of fishing gear for trawlers in rougher terrain and/or of boat damage in these still poorly charted waters. This pattern matches known fishing behavior of trawl and line fishers in this area (Gribble and Robertson, 1998).

Scenarios

Three scenarios were simulated, as follows. (i) The Null scenario, in which no MPA closure was applied and trophic guilds were allowed to distribute across the various spatially explicit habitat types including natural *de facto* refugia. (ii) Full MPA scenario, in which the large GBRMP "no take" zone was applied with full compliance assumed (see Figure 4A); and (iii) "Realistic" MPA scenario, which uses the known spatial pattern of compliance with the closure (Gribble and Robertson, 1998; see Fig 4B)

A.



B.

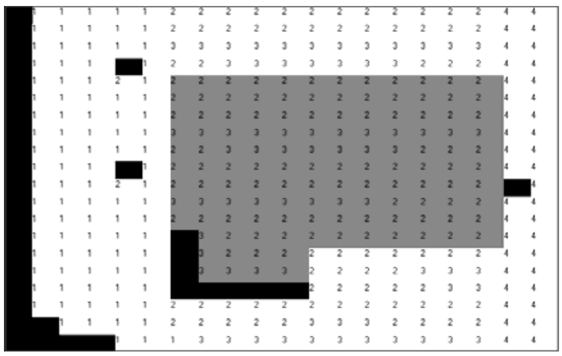


Figure 4. Virtual maps of MPA scenarios applied to the GBR cross-shelf. **A**: Full MPA cross-shelf closure

(grey shading is closed to fishing). **B**: "Realistic" MPA based on known fishing effort patterns. After Gribble and Robertson (1998).

Results -ecosystem modeling

The results are presented in Appendix A, Table I, where changes in biomass are compared for four "example" trophic guilds across the respective scenarios. In a balanced temporal simulation with all factors including fishing effort kept constant, the relative change in biomass would be 1, i.e. the start and finish biomass would be equal. The effect of adding a spatial component would show as changes in the delta biomass (Δb), with > 1 representing an increase in relative biomass and < 1 indicating a decrease in relative biomass.

Null scenario
In this scenario, and *de facto* refugia were created in outer reef and lagoon areas by:
Trawl fleet concentrated effort in the inner lagoon and inter-reef gutters, consistent with the availability of target prawn species and increasing costs of trawling offshore.
The line fishery fleet was spread across the reef/shoal area but concentrated on the most accessible inner reef edge.

Large groupers (see appendix A, Table 1) were restricted to the main reefs/shoals and offshore lagoon. Seabirds were reasonably well spread across the study area with increased density at the inner edge of the reef/shoal zone, while small fish omnivores were also well spread out but with relatively lower density in those areas with highest trawling effort (inner lagoon and inter-reef areas). Sea turtle species were concentrated in the outer reef/shoal zone. The addition of *de facto* spatial refugia to the basic temporal simulation had the overall effect of favoring the vulnerable species and/or those of high conservation value such as turtles and large groupers. But the scavenger/coloniser species which prefer the more disturbed environments did less well. The small drop in biomass of small fish omnivores (the main component of discarded trawl bycatch) may seem counter- intuitive but is attributable to the spatial concentration of trawl effort in their prime habitat.

Full MPA scenario (Figure 4A).
Compliant with MPA closures, trawling was concentrated in the open sections of the inner lagoon, grading across the reef/shoal area to zero in the outer lagoon. Line fishing was concentrated in the reef/shoal zone along the northern and southern borders of the MPA closure representing a redistribution of effort from within the closure. In this scenario, large groupers were no longer restricted to the main reefs/shoals and offshore lagoon; their distribution spread and density increased from these zones into the inter-reef. Seabirds concentrated along the northern and southern borders, associated with fishing activity and bycatch discard. The removal of trawling resulted in an increase in density and area of distribution of small fish omnivores in the MPA, but the increased (displaced) trawl effort along the borders caused an apparent depletion on the northern and southern borders. Sea turtles were notable winners from the MPA, in both density and spatial distribution, but there were very small biomass at the start of the simulation, which meant there was a dramatic change in the relative biomass (Appendix A, Table 1). Overall, vulnerable species were favoured by the MPA, while the

reverse was the case for scavengers and coloniser species.

"Realistic" MPA scenario(Figure 4B)
Under this scenario, trawl effort concentrated along the inner lagoon and northern and southern borders. The model predicted that the highest level of illegal trawling would take place in the inner lagoon in which high value target species are distributed. The line fleet's non-compliance was restricted to the northern and southern borders. Distribution of large groupers was intermediate compared to the previous two scenarios, with biomass down on the northern reef shoals but maintained in the protected core. Seabirds redistributed to follow the trawl fishing effort along the inshore edge of the reef/shoal zone. Small fish omnivores were depleted in the inner lagoon where trawling was concentrated; the drop in biomass again seems counter-intuitive but may be explained by the displaced trawl effort in the inner lagoon presenting a "gauntlet" or barrier to their normal movement. The density and distribution of turtles increased relative to the Null scenario, with these animals spreading into the core protected area away from the border edge effects.

Discussion

Ecosystem modelling can be an important tool to inform policy for the management of fisheries resources and of the impact of spatial zoning/closures (e.g., MPA's). Such modelling provides a simplified and "virtual" version of real-life complex ecosystem dynamics, therefore the results of the modelling should be taken as indicative of potential outcomes. As this case study illustrates; when introducing closures for fisheries management or biodiversity conservation purposes, we need to be mindful of the complexity of these ecosystems and the ramifications of area closures for different species groups.

The spatial closures in the GBRMP appears to be selectively beneficial to different trophic guilds. For example, opportunistic trawled prawn species fared better in scenarios with the Null and "Realistic" MPA closures compared to the theoretical MPA closure. In contrast, species targeted by the reef line fishery (including the Scombrids/jacks and large schooling fish trophic guilds) did relatively better under the MPA scenarios due to a combination of habitat protection and the fact that their life history makes them more susceptible to severe depletion. Overall, the higher trophic levels benefited from the MPA closures, while the lower trophic level species, taken mainly by the prawn fishery, did not.

References.

Christensen, V., Walters C., and Pauly, D. (2000). Ecopath with Ecosim: a User's Guide, October 2000 Edition. Fisheries Centre, University of British Columbia, Vancouver, Canada and ICLARM, Penang, Malaysia. 130 p.

Gribble N.A., (2005a) GBR Linked Ecosystem Model computer program . **Electronic Publication.** http://www.ecopath.org/index.php?name=Models&sub=model&modelID=65

Gribble, N. A. (2005b) **CD** Ecosystem modeling of the Great Barrier Reef: A balanced trophic biomass approach. In Zerger, A. and Argent, R.M. (eds) MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2005, pp. 170-176.

ISBN: 0-9758400-2-9. http://www.mssanz.org.au/modsim05/papers/ascough_1.pdf
Gribble, N. A. (2003) GBR-prawn: modelling ecosystem impacts of changes in fisheries management of the commercial prawn (shrimp) trawl fishery in the northern Great Barrier Reef. Fisheries Research 65(1-3): 493-506
Gribble N. A. (2000). "A model of the ecosystem, and associated penaeid prawn community in the far northern Great Barrier Reef'. In (E. Wolanski editor) Oceanographic Processes of Coral Reefs: Physical and Biological links in the Great Barrier Reef. CRC Press NY pp 356
Gribble, N.A., and Robertson, J. (1998). Fishing effort in the Far Northern Cross-shelf Closure of the Great Barrier Reef Marine Park: the effectiveness of area closures. Journal of Environmental Management. 52,53-67

APPENDIX A

Table 1. Simulated changes in Biomass (Δb) for each major trophic guild in the ECOPATH model of the GBR. (i) Null simulation with no MPA (but with *de facto* refugia); (ii) Full "cross-shelf closure" MPA; (iii) "Realistic" MPA based on known fishing effort patterns.

Trophic Guild	Biomass (Start t/km^2)	(i) (Δb) No MPA	(ii) (Δb) Full MPA	(iii) (Δb) "Realistic" MPA
Cephalopods	0.333	0.95	0.96	0.94
Large groupers	0.032	1.90	2.87	1.97
Scombrids/jacks	2.026	1.03	1.08	1.08
Seabirds	0.014	0.77	0.90	0.82
Large sharks/rays	0.564	0.97	0.90	0.93
Small schooling fish	3.062	0.87	0.86	0.97
Large fish carnivores	1.795	0.97	0.94	0.98
Large schooling fish	0.590	0.88	0.92	0.96
P. longistylus	0.088	1.03	0.89	0.88
Other prawns	0.234	1.18	1.27	1.04
P. esculentus	0.176	0.88	0.56	1.02
Small fish omnivore	2.557	0.93	0.95	0.79
Sea turtles	0.009	2.53	5.12	2.52
Crustaceans	2.822	0.95	1.00	0.97
M. endeavouri	0.144	0.80	0.52	0.84
Echinoderms	8.397	0.97	0.94	0.99
Benthic mollusc/worms	10.942	0.96	0.95	0.98
Zooplankton	3.739	0.97	0.97	0.99
Sessile animals	31.300	1.01	1.04	1.00
Fish herbivore	7.435	0.98	0.95	0.95
Decomposer/microfauna	5.996	0.98	0.98	0.98
Phytoplankton	7.652	0.98	0.98	0.97
Benthic autotrophs	174.748	0.99	0.99	1.00
Detritus/discards	53.513	0.83	1.12	0.90
Detritus	40.060	0.99	0.99	0.99
Total		0.96	1.01	0.98