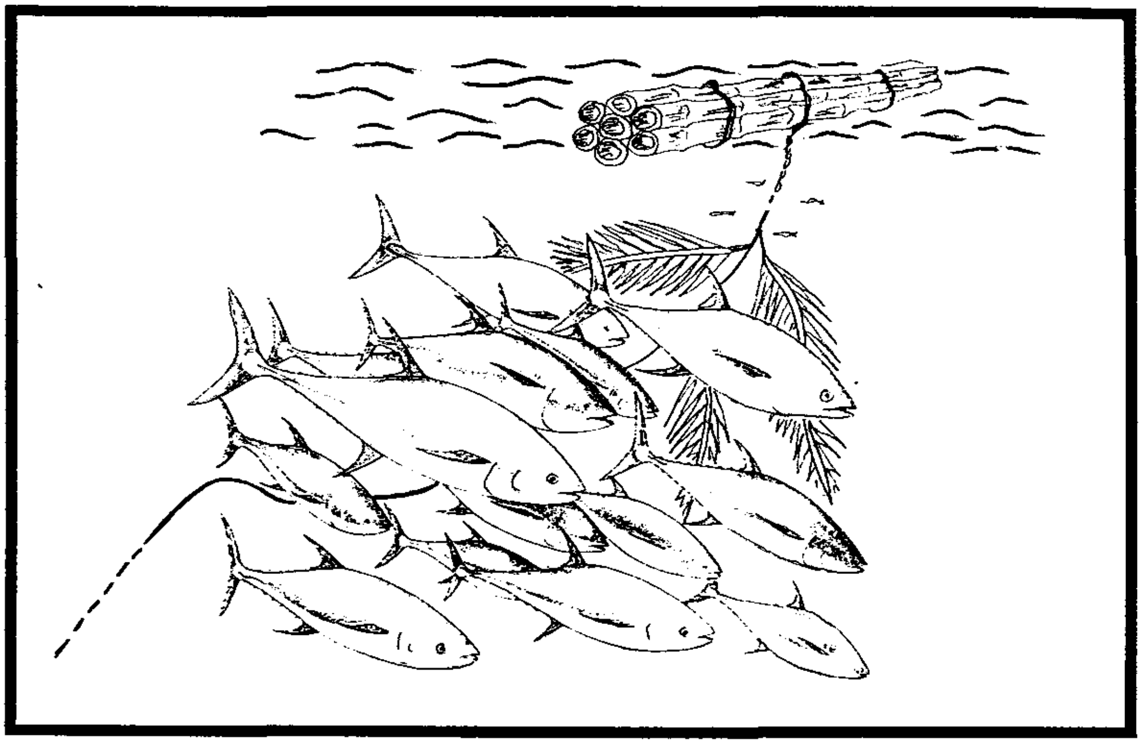
THE ASSESSMENT OF THE INTERACTION BETWEEN FISH AGGREGATING DEVICES AND ARTISANAL FISHERIES

Document 5: A Review of Bioeconomic and Sociological FAD Modelling, with Recommendations for Future Research Projects.



FISHERIES MANAGEMENT SCIENCE PROGRAMME

OVERSEAS DEVELOPMENT ADMINISTRATION

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1. INTRODUCTION

Fishermen have long been aware that fish are attracted to floating objects and that consequently catch per unit effort around such objects is higher than in the open sea. Having made this observation, it was sensible for fishermen to manufacture floating objects and moor them in suitable places for regular use. Such fish aggregation devices (FADs) have been used, particularly by artisanal fishermen, for many years. The last few decades, especially, have seen an explosion in their use, as fishermen and fisheries managers look for new and easier ways to improve catches and profits of their industry.

Once FADs had become more important in fisheries, questions about them arose which acted as drivers for research. As their use became more widespread, the scope of the issues that they highlighted broadened, thereby changing the thrust of the research effort. The purpose of this document is to summarize the current state of FAD knowledge and identify directions for future research, concentrating on the biological, social and economic aspects of their use.

The next section of this review is a brief history of FAD research and research strategy, describing the issues that have driven and are still driving research into FADs. Section 3 is a description and assessment of the current state of the art, and provides a foundation for section 4, in which future research directions are discussed. Section 5 contains some recommendations for research projects which would contribute meaningfully to the solution of the issues raised in section 2.

2. HISTORY OF FAD RESEARCH

In many cases, researchers and fisheries managers became involved in FAD projects somewhat after the event, with fishermen already deploying FADs and having introduced many innovations in their use. The initial impetus for research was a desire to maximise benefits and determine the ideal design, placement and spacing of the FADs. High rates of FAD loss particularly prompted studies on construction methods aimed at increasing their lifespan. Success of FADs in some areas induced fishermen and managers in other areas to try for the same benefits to their fisheries.

In some places where FADs were newly deployed they became popular with fishermen while in others they remained unused, leading scientists to try to understand which factors caused a FAD to be successful. Measures of effectiveness for FADs had to be defined, and existing FADs evaluated against these criteria.

The records of the early experiences of fisheries managers were mostly anecdotal, and were often published in the grey literature. Many claims were made about the benefits of FADs and the success of FAD projects, but very few of them were substantiated by any form of rigorous analysis.

In their landmark paper published in 1985, Bohnsack and Sutherland described the trends in artificial reef research over the previous fifty years and laid down guidelines for future research directions as well as methodology. They pointed out that only 31% of the literature of the time had been published in peer reviewed journals, so much of the work that has been done is inaccessible to most researchers. The two most common topics amongst their 413 references were historical program descriptions for specific geographical areas and general, non-technical articles on artificial reefs. Much of the earliest research that was done concentrated on the design, construction, deployment and maintenance of FADs. Biological studies focused initially on the ecology, behaviour and production of species at FADs and tended to be descriptive or experimental rather than theoretical. Fewer than 4% of the research papers reviewed were concerned with social or economic issues. Bohnsack and Sutherland identified shortcomings in the experimental and analytical methods that had been used and prioritised areas where research effort was needed. Much of the more recent work has been done within the framework which they proposed.

Typical questions that have arisen about existing FADs are:

- which user groups use a FAD and what is the intensity of use?
- is the FAD meeting the needs of those it was designed to serve?
- has the FAD had the social and economic impact it was designed to have?
- are the benefits sustainable?
- has the expenditure of funds for FAD development been efficient, particularly when compared with other fishery management options?
- what rules and regulations can be used to assure that the deployment and use of a FAD are consistent with society's objectives?

In planning FAD programs, we need to:

- decide when it is or is not appropriate to use FADs;
- quantify the benefits that should accrue;
- improve the design, placement and management of FADs to maximise benefits;
- initiate monitoring and evaluation programs to answer the first set of questions.

It is particularly important to establish under what circumstances the benefits to be gained from FADs are truly sustainable. One of the earliest assumptions was that the increased fish density around FADs was the result of increased biomass production due to the shelter and food that they provided. This implied that deploying FADs would relieve the fishing pressure at nearby natural reefs, or at least increase catches without disturbing neighbouring fisheries. This belief gradually came to be questioned and it has become important to establish the contribution to FAD populations of:

- increased production;
- redistribution of an unexploited stock;
- redistribution of an already exploited stock.

There is now concern that FADs may have been responsible for decreased catches in the Phillipines, and various models and studies have suggested that FADs might exacerbate growth overfishing, expose juvenile fish to exploitation or predation, or otherwise have adverse effects on the ecology of the area. Traditional fisheries assessment tools do not take account of the spatial distribution of stocks. This is a disadvantage when assessing any schooling species - even more so when artificial FADs begin to be deployed on a significant scale. Fisheries managers have a need for new models accounting for the nature of FAD influence on population dynamics and behaviour.

A problem that surfaced with increased deployment of FADs was that of conflict between users of different gear types or users from different types of industries, or because of congestion at the FAD site. Where FADs have been deployed by individuals or groups they wish to have exclusive rights to fish there, or to claim a portion of the catch taken. Where FADs are deployed by the state, individuals either do not protect them as they would their own property, or occasionally claim ownership. Most countries do not have specific laws relating to the deployment or use of FADs, so general legal principles contained in, for example, property, maritime and fishery laws must apply. These are often not sufficient to cope with the problems that FADs can bring. On the other hand, in certain areas a comfortable symbiosis has evolved between user groups. It is important to understand the complexities of these relationships in order to encourage harmony at other locations.

It should be mentioned that artificial reefs have generally attracted more research than FADs, although much of the reef work is applicable to FADs, and has thus been included here.

3. THE STATE OF THE ART

FADs are just one of many tools for fisheries management and development and should thus be evaluated against other management and development methods. In practise, they could well be considered as just another fishing gear.

The work that has been done to date seems to indicate that where a resource is underexploited, FADs can bring higher catches and revenues. However, where a resource is fully exploited, consequences can range from increased conflict to stagnant, lower or redistributed catches, revenues or incomes.

□ **Socio-economics**

Techniques exist that can be used for assessing some aspects of the social performance of FADs. Monitoring, impact assessment and efficiency analysis have long been used in water evaluation and occasionally in fishery development projects, but their application to FAD planning and evaluation has been sparse. In his chapter of the book "Artificial habitats for marine and freshwater fisheries", JW Milon provides a guide to the application of these methods to artificial habitat projects. He also gives references to more detailed works on social and economic evaluation methods as well as examples from the artificial habitat literature. Here is his overview of the topics discussed:

Type of evaluation	Purpose	Primary methods
Monitoring	Identify habitat user groups, usage rates and determinants of use	Data collection and analysis from site observation and surveys
Impact	Measure changes in economic activity or social structures	Economic base or input-output analysis; social impact analysis
Efficiency	Determine whether project provides desired outcomes for least-cost or whether monetized value or outcome exceeds cost	Cost-effectiveness or cost-benefit analysis

The FAD handbook produced as part of the MRAG/ODA Research Programme has been designed to make many of these procedures accessible to fisheries managers.

□ **Bio-economics**

Optimal control methods for bioeconomics have also been applied to FAD fisheries. These are methods for finding a set of control parameters (within allowable limits) that maximise a given function, known as the cost function. This function usually represents a sum of net benefits for different user groups, while the control parameters would be fishing effort or seasons, minimum size etc.

This sort of model has been used by a number of authors to examine conflicts between sport and commercial fishing. These techniques should also be effective for analysing conflicts between users of different gears. A theoretical inquiry was performed by Bishop and Samples in 1980. Their models show that having a number of different users of a resource may be optimal. The important point is also made that the relative economic merits of sport and recreational fishing should be compared at various fish population levels, so that the comparison can eventually be made at the optimal population level. A similar model by McConnell and Sutinen shows that a critical parameter for allocating between commercial and recreational fishing effort is the own-price elasticity of effort in each.

These methods do have their limitations. The management ideal must be captured as a goal or cost function, usually in the form of economic efficiency. The demand for recreational fishing is much more complex than is allowed for in such models as yet. Situations where one gear has open access while another has not could complicate issues. Also, in some cases, success of one group may have a positive influence on the other, for example where commercial catches are supplied to restaurants which cater to tourists, including recreational fishermen. These complications must still be addressed.

□ **Population Dynamics**

FADs are mostly used to catch tuna and similar home ranging, migratory, pelagic predators. The question of why and how they work is still open to debate. Fish are attracted to them as a result of a behavioural preference; unlike some artificial reefs, it seems that there is no significant increase in production at FADs. Reasons that have been put forward for this attraction are:

- algae that grow on FADs provide food or attract food species;
- they act as a base from which to forage;
- FADs provide shelter from predators;
- they provide shade;
- they define resting places;
- they attract sufficient fish to spawn effectively;
- they serve as orientation and navigation aids;
- fish are attracted out of curiosity;
- the fish form a structure similar to bees or ants nests, passing information about food or local conditions.

These suggestions are not all compatible, for instance, providing shelter from predators and being a good food source are uncomplimentary properties. It has been pointed out that although the instinct to aggregate around logs presumably evolved because of some selective advantage, FADs may provide cues beyond the evolutionary experience of fishes and elicit responses that are not necessarily adaptive.

The first model of tuna aggregation was proposed by Clark and Mangel in 1979, working on tunas associated with marine mammals. The model was subsequently expanded and adapted for FADs by Samples and Sproul in 1985, and by Hilborn and Medley in 1991. These last two are thus models of the dynamic interrelationship between an underlying population of fish and a subpopulation which associates with a network of FADs.

The Samples and Sproul model incorporates a Schaefer model for the base population (including an intrinsic growth rate and carrying capacity). It requires estimates of the aggregation rate to the FADs (a rate assumed to be proportional to the biomass of the underlying population) and the migration rate from the FADs to the base population (a rate proportional to the standing stock size at the FAD). FADs are modelled as independent and equally attractive, which is clearly not the case in practise. Fishing effort and catchability at the FADs and the standing stock are required. The model can then produce the equilibrium values of biomass and sustainable yields from the FADs and the base population. If the unit fish price and cost per unit of standardised effort are added to the model, optimum effort levels at the FADs and base stock can be calculated.

The results of this model suggest that where effort is unregulated, installation of FAD networks will not generally increase fishermen's aggregate profit. In fact, under certain circumstances (e.g. where fishing is low cost and efficient, and FADs are good at aggregating fish) there could be unintended results such as decrease in employment, harvest levels and sustained gross revenues. There is even the possibility of extinction of the background stock. This model could be used to analyse specific fisheries to see whether there is a need for strategies to control effort, and what sort of management (e.g. private property rights, licence fees) would be appropriate.

The model developed by Hilborn and Medley uses constant recruitment rather than a production model, and assumes a migration rate to the FADs which is dependent on the unassociated population size. They model pulse fishing as practised by purse seiners rotating between a controllable number of FADs. Outputs include an optimal spacing pattern for the FADs.

A disturbing result of their model is the prediction that catch will drop off when too many FADs are deployed. A game theoretical analysis of two fishing boats pulse fishing with FADs shows that the dynamics of a FAD fishery can be worse economically than an open access fishery; equilibrium is at a point where both boats make negative profits.

Both of the above models have improved our understanding of the relationships in a FAD fishery. Although work must still be done to validate them, they can already provide important insights as well as warnings of possible dangers to a fishery.

□ **Spatially Distributed Models**

In 1989, Mullen published a model of tuna movement and aggregation which, although it was done without reference to FADs, is of relevance to FAD modelling. He used a diffusion model similar to certain optimal foraging models but with the diffusivity as a linear function of local saturation (i.e. the ratio of local biomass to local carrying capacity). The modelled tuna bahave in ways that are compatible with observation, but whether the modelled process represents reality or merely imitates it is unclear.

The model suggests that fishing at places of high carrying capacity transforms those places into sinks for the whole region, i.e. abundance is diminished in neighbouring areas as fish move in to replace those removed by fishing. Application of the model indicates that where low effort is exerted with low efficiency at a centre of aggregation (such as an island), CPUE can halve once a high technology fleet is allowed to fish with high effort and efficiency within migration range of that centre. Similarly, a manager responsible for one area out of a number between which fish migrate, faces the dilemma that reducing the catch in his area reduces immigration and enhances emigration. High rates of exploitation thus effectively enlarge the range of his fishery.

Kleiber and Hampton have developed a population dynamics model which includes tuna movement over a geographical area. The model was designed to be fitted to data from a major tagging project in the Solomon Islands, and includes a model of the effect of FADs on tuna movement. The motion is modelled with constant diffusivity which can be reduced by the presence of FADs or islands. Preliminary results show that the model can fit the tag recovery data reasonably well, with sensible values for its parameters. Where FAD effects are ignored, fits are markedly worse, so the model clearly captures some influence that FADs have on tuna behaviour. This work is due to be published soon in the Can. J. Fish. Aquat. Sci.

4. DIRECTIONS FOR FUTURE RESEARCH

Given the state of FAD knowledge at present, we recommend that the following three categories be equally represented in future work:

□ **Apply what is known**

In many fields of scientific endeavour, a span of years or even decades exists between completion of a piece of research and its application by those for whom it was devised. Fisheries management is no different, and the pressure of daily tasks often denies managers the time to keep up to date with the latest research. Even if they do, the task of turning a process, idea or model into a practical application to be used with confidence is daunting for all but the most experienced and well resourced managers.

If the benefits of previous work are to be realised it is essential that projects be regularly initiated with the sole aim of disseminating existing information. This may in some cases also involve developing methods for applying existing theory. The methods could be incorporated into daily use by means of:

- dedicated, stand alone, computer applications;
- simple booklets for each type of analysis with step by step guides, examples and cautions on limitations of the methods;
- expert systems for question and answer types of decision making;
- workshops and training sessions;
- expert advice for sensitive or difficult fisheries.

The handbook and spreadsheet model produced as part of the MRAG/ODA Research Programme form a good example of this sort of work.

□ **Test what is surmised**

A number of models have been devised and published in the literature as possible descriptions of aspects of FAD, fish and fisherman dynamics. While these models can, and already do, provide important insights into a fishery, many conclusions are dependent on the validity of the assumptions that are central to the model.

Some models for exchange of biomass between FADs and a base stock were discussed in the previous section. The various models have slightly different and sometimes contradictory assumptions, so it would be worthwhile to devise some experimental projects which might identify the correct process. For example, it would be useful to know whether the recruitment rate to FADs depends on the total stock size or only that portion of the stock unassociated with FADs. At present, data which could confirm one or the other is not available.

Mullen's diffusion model appears to describe observed tuna behaviour fairly satisfactorily. If the model is representative, we would expect to see certain other effects which have not been tested before, so experiments to look for these effects would be useful. This model has the potential to have an significant impact on the way some fisheries are managed, and could also serve as an important base for further work.

□ **Refine current theories and develop new ones**

On the biological side, we still need to determine the manner in which FADs attract fishes and examine the interactions of fish with the surrounding habitat. For example, it is possible that FADs do not need to provide food but they must be in areas where the right food resources occur. It is important to develop predictive models that can be tested and would be useful to set up experimental zones of FADs for such research. Models incorporating spatial distribution and density will be better suited to the analysis of FAD fisheries. More use could be made of models and theories from related disciplines such as biogeographic theory, optimal foraging and diffusion theory.

Socio-economic theory as applied to FADs is still young and much work is still needed to quantify their direct and indirect economic and social benefits. If FADs are to be managed in such a way as to reduce conflict, then legal studies on liabilities and property rights should be combined with policy-related research on ownership and use of FADs. Further work on optimum design and placement of FADs must be done, especially once goals and measures of effectiveness have been refined. There will be significant differences between the artisanal and industrial fishery approaches, especially as regards scale, goals and other sociological issues.

Optimal control models typically use the maximisation of profits as the goal according to which control parameters are chosen. An investigation into the influence different goals would have on the outputs of such models could be significant. Some researchers have even expressed concern that optimisation's overemphasis of the efficiency goal can lead to problems, but feel that it is important that work with such goals be done since efficiency already plays a role in policy debate. There should be a search for alternatives, however.

Most importantly, there is much significant work that could be done by interdisciplinary teams of sociologists, biologists, economists and mathematicians. The application of FADs touches on so many fields, it is unproductive for specialists to work in isolation on those aspects of relevance to their fields. Combining the existing expertise could yield models, processes and insights that are invaluable in helping to develop and manage FAD fisheries sensitively as well as effectively.

5. *RECOMMENDATIONS FOR FUTURE RESEARCH*

In this section recommendations are made for the specification of projects or project components which would contribute meaningfully to FAD research and its application to fisheries development and management problems. The philosophy behind these proposals is that we should build upon the FAD work that has already been done, in ways that specifically address the most pressing open questions about the nature and use of FADs.

□ **Dissemination of information**

There should be regular projects to interpret and disseminate information from the literature to fisheries managers.

- MCDM and expert systems:

  Develop a 'multi-criterion decision making' based expert system to assist with all decision making relating to FAD development and planning. This could be based on the FAD handbook and report accompanying this document. Sociological analysis using the systemic approach should be included. The system should not operate as a 'black box', but rather provide a framework within which all relevant questions are addressed while showing clearly how answers are derived and how goals and priorities affect decisions.

- Analytical Methods

  Develop software to do sensitivity analyses on
  - parameters in biomass exchange models for estimating yields and optimal effort levels;
  - assumptions on which cost benefit analyses are based

  or

  Write a thorough, step-by-step description of how to implement such a sensitivity model in a spreadsheet.

□ **Investigation of the aggregation effect**

It is important to quantify how fish aggregate and disperse, so that models can be applied in fisheries management. In the process, clues as to why they behave in this way may also emerge. Two approaches are recommended here - one to examine the relationships expressed in the biomass exchange models of FADs and another to look for the effects predicted by diffusion and optimal foraging models.

The first approach would be to try to determine at what rate fish accumulate at FADs, and what relation this rate has to the biomasses of fish at the FADs and in the underlying stock. This would include quantifying the loss of fish from the FAD to determine whether it is a constant or density dependent proportion of the biomass at the FAD. Seasonal effects would have to be accommodated. Different age/length-classes may well aggregate in different ways, and this should be quantified.

For a start, where possible, use should be made of the data sets that exist, e.g. the data from the Solomon Islands industrial purse seine fishery. Further data would have to be collected by monitoring a number of FADs and measuring how the number of fish (in various length-classes) at each FAD changes over time. A good pre-FAD dataset would be useful. Measurements could be made by visual survey, sighting counts, or by taking acoustic soundings at the FADs. Water samples, plankton net samples, climatological and oceanographic data should be collected so that any correlations that exist can be detected. A series of experimental, unfished FADs would be ideal but expensive. Whether experimental or commercially exploited, the FADs should be chosen/placed so as to cover as many of the following categories as possible:

- Deep water FADs that are fished by purse seiners are regularly stripped of most of their fish. The manner and rates at which those FADs are repopulated could be measured. Length and age composition of the catch could also be correlated with the number of days since it was last fished, to see what patterns emerge.

- FADs that are fairly lightly used by artisanal fishermen would be interesting because they are more likely to be close to equilibrium. Catches as well as population movements would have to be monitored.

- Neritic (shallow water) pelagics such as bonito and frigate mackerel seem to be less migratory than others. In such positions it might be possible to estimate population biomass of the base stock. Measurements of migration to and from FADs in such areas could be correlated to the base stock and FAD biomass. The FAD and species would have to be chosen carefully because the aggregation effect is likely to be weaker in these areas.

- Sites where FADs are fairly densely placed would be particularly interesting if tuna were also tagged in order to watch them move between the FADs. Commercial FADs are generally placed further apart than the 'safe distance' of about 10 miles. To measure movement between FADs that are closer than that, an experimental setup would be needed. The ideal would be to observe a matrix of FADs about 4-5 miles apart, and then to remove intermediate FADs and monitor the effect on distributions.

- It has been reported that tuna schooling behaviour is different in different oceans. Old fish tend to school around mammals in the Indian and Atlantic oceans whereas younger ones (and often mixed schools) are found around FADs in the West Pacific. Differences between the oceans, such as quantity of floating objects or behaviour of currents, should be investigated; any correlations could possibly provide insights into aggregation behaviour.

The second approach is aimed at testing diffusivity models and should begin with a study to estimate which of the predicted effects would be observable at all, given statistical variation. If the results are favourable, one could:

- determine whether heavy fishing in an area enhances immigration to that area i.e. whether FAD recruitment is density dependent. This could be added to the first approach, by including FADs that are heavily but continuously fished, rather than pulse fished.

- look to see whether there are fewer fish in the regions adjacent to a FAD catchment area than there are in the open ocean. This would require estimates of abundance at various distances from the FAD. Either research catches or sonar would have to be used, since fishermen will not fish in areas of known lower abundance.

- estimate deviation from constant diffusivity at certain times. The first group of biomass studies could be extended to include sesonal variation in the aggregation effect.

- determine whether there is a component of migration that is simply the result of diffusion combined with seasonal movement of the tolerable environment. This would require investigation of the oceanographic and climatological changes that take place along the known migration routes of tuna. If correlations exist, a diffusion model could be set up to try to imitate known tuna migratory behaviour using only diffusivity.

- if the structure of the model seems correct, estimate the diffusivity constant empirically for particular fisheries. Estimates of diffusivity have been reported in the literature. Methods for making such estimates should be investigated and applied adaptively to real fisheries.

□ **Selecting figures of merit for FAD effectiveness analysis**

Most bioeconomic models of conflict between user groups use optimisations based solely on the goals of economic efficiency. Other goals are harder to formulate and vary greatly between fisheries. It is recommended that an interdisciplinary team of biologists, economists, social scientists and mathematicians investigate this issue. Goal programming, which can handle multiple goals, may be more useful than single-criterion optimisation techniques. The possibility of using multi-criterion decision making techniques, game theory or the systemic approach as a procedure for determining goal functions should be investigated.

An adaptive research phase to implement developed techniques in specific fisheries would be important. It is possible that a weighting of objectives which is revised iteratively according to observed data may be more useful than a fixed framework.

□ **Biological modelling**

There are a number of ways in which existing biological models could be expanded to make them more representative of FAD fishing.

- Develop a bioeconomic model along the lines of the existing biomass exchange models (Samples and Sproul, Hilborn and Medley) but accounting for multiple cohorts where specific year classes are preferentially attracted to FADs. This sort of age-linked behaviour is considered very likely. The project should examine management implications of such a differentiation.

- Expand on Hilborn and Medley's model by including the spatial distribution of FADs and allowing for boats to search for the largest schools before making a set. Include a stochastic arrival and departure model, for example assuming fish come and go in schools that are small subsets of the stock population. It would be interesting to include a diffusion or optimal foraging models and see how this influences biomass equilibria.

- Look at the dynamics of games between multiple boats placing FADs with more subtle decision criteria than the ones used previously, for example each one deciding when it would be advantageous to place more FADs.

- Refine existing spatially distributed models to include ideas and concepts which have been successfully incorporated in other types of models, such as density dependent diffusivity, schooling and pulse fishing.

Many of these modelling projects would benefit from contributions from many disciplines. Research directions which span more than one field of technical expertise are usually the slowest to mature, but it is from such fields that whole new directions of scientific endeavour often emerge.

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