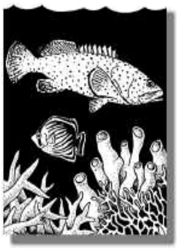

Monitoring and managing spawning aggregations: Methods and challenges

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Introduction

The increased use of reef fish spawning aggregations as sources of food fish, and their susceptibility to overfishing make it increasingly important that such aggregations be managed and monitored. While we recognize that various options for managing spawning aggregations exist, whether through spatial or seasonal protection, effectively assessing the status of aggregations over time remains a challenge. Such assessment is essential for management but surprisingly difficult to achieve, largely because fishery-dependent data may not always indicate the true status of the fishery, and fishery-independent data can be misleading due to rapid changes in fish numbers during a single aggregation. In large aggregations, simply counting the fish moving about on the bottom can be a challenge. This article discusses some of the more obvious problems and needs, and is extracted from two articles that should be consulted for more information (Colin et al. 2003; Sadovy and Domeier 2005).

Unfortunately, there is no "one size fits all" approach to monitoring or managing commercially exploited, aggregating reef fish. Some species are naturally more vulnerable or more likely to be exposed to heavy fishing pressure throughout the year than others and may need to be assessed and managed during both aggregation and non-aggregation periods. One example would be species that form just a few large and highly concentrated aggregations. In contrast, a species such as the coralgrouper, *Plectropomus leopardus*, which forms relatively small aggregations (often several on one reef, in close proximity to one another) may not be so severely affected by the loss of a few small aggregations. Species of either type may be heavily targeted throughout the year, even when not spawning. Some species can be more suitably protected through seasonal measures, others by site-based protection, and all should be monitored in some way to determine whether the management option selected is effective or needs to be modified.

Management

Currently, the most commonly applied fisheries management measures for species that aggregate to spawn are seasonal bans on catches or sales and temporary aggregation site closures (Fig. 1). Marine protected areas have not typically incorporated spawning aggregations in their design, although this seems likely to change in the future. Sales bans can be a practical approach under certain conditions, such as when surveillance of spawning sites is not possible, if many sites are not yet known (indeed, in many areas the best protection that aggregation sites may have is to remain unknown), or if landings are concentrated in a few public markets. Protection of spawning aggregation sites during the spawning season, or their incorporation into marine protected areas, would not protect species also vulnerable while migrating en route to aggregations, or that are heavily fished at other times of the year. Consequently, the protective measure(s) selected need to take such considerations into account.

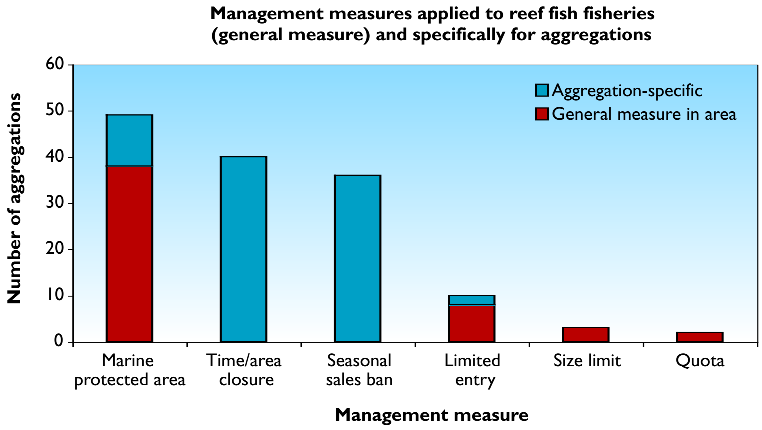

Figure 1. Available data on management associated with spawning aggregations or reef fish globally showed that management that specifically targeted protection of aggregations tended to involve temporary closures of spawning sites, sometimes associated with seasonal sales bans for the target species. *Source: Society for the Conservation of Reef Fish Aggregations Database www.SCRFA.org*

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Fishery-dependent monitoring

Long-term monitoring is an essential component of successful management, and is a deceptively difficult challenge in the case of aggregation-spawners. Without monitoring, the effectiveness of management intervention cannot be assessed, and adaptive management cannot progress. Monitoring involves assessment of abundance over time, which can help to determine the seasonality of aggregations, and assess changes in numbers over time due to fishing, management or other factors. Because absolute numbers of fish are hard to determine, abundance in fisheries is usually determined by a proxy, such as catch per unit of effort (CPUE), which is typically assumed to be directly proportional to abundance. CPUE assessment requires both an estimate of fishing effort and an estimate of fish catch. The way in which fish and fishers are distributed in space and time can impact both catches and the relationship between CPUE and abundance, however. This is particularly important when the behaviour of fish changes in a predictable way, such as in the case of temporary aggregating behaviour.

When large numbers of fish concentrate periodically and predictably, the relationship between CPUE and abundance may not be directly proportional. If an aggregation-based fishery is not oversaturated (i.e. fishers are taking as many fish as they possibly can), CPUE is likely to remain stable even as the actual number of aggregated fish declines. This is a condition known as "hyperstability" and is a major problem for both monitoring and management (Hilborn and Walters 1992). When hyperstability occurs, fishers may resist management in the absence of evidence of dwindling catches; for managers it poses the problem that a monitored stock can decline without any change in aggregation CPUE that would indicate problems until the stock begins to collapse (Fig. 2). Monitoring cannot rely solely on CPUE measures, particularly for spawning aggregations.

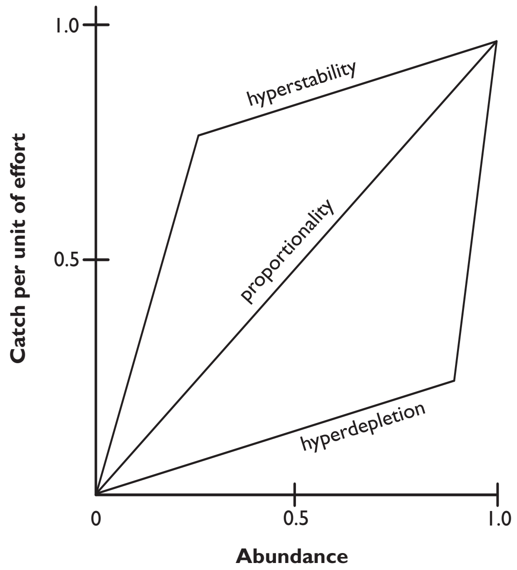

Figure 2. **Relationships between catch per unit of effort (CPUE) and abundance under: hyperstability (when fish or fisher behaviour results in elevated CPUE even as fish abundance declines until the stock starts to collapse) and hyperdepletion (when catches fall disproportionately with effort).**
Source: Sadovy and Domeier 2005, based on Hilborn and Walters 1992.

Fishery-independent monitoring

While seemingly straightforward, counting aggregating fish in the water and calculating densities and changes in fish numbers over time can be a challenge, both in terms of monitoring design and execution. Nonetheless, the information to be gained can be very valuable for detecting changes in numbers over time, especially if part of a long-term monitoring program, and is critical for understanding the effects of management.

Why is it such a challenge to meaningfully monitor aggregating fish? As we have come to learn more about aggregations of different fish species, or the same species over time, we have also come to understand how variable aggregations can be in time and space. For example, fish numbers can vary within a given aggregation site from year to year, and even from day to day, as can the timing of aggregation formation in a given year, or in relation to moon phase. The timing of aggregation formation of the same species can even vary among different aggregations located within just 20 km of each other, and certainly within a country or region. Understanding such variations is obviously very important when seasonal protection is introduced.

The problem of counting fish

The key question is how to count fish with an acceptable degree of precision so that information, over time and across space, is comparable and meaningful. This article discusses the most commonly used method, underwater visual census (UVC), but other methods, such as video recording, might also be possible under some circumstances. If aggregations are small or fish are few, it might be possible to count all the fish. When there are too many fish to count, an estimate can be made of the total number by counting the number of fish in a small and known area of an aggregation and extrapolating from this number in accordance with an estimate of the total area over which the aggregation extends (see below). There is no easy way to check the accuracy of such estimates, so careful design and execution of surveys and careful analysis of survey results (including consideration of possible errors) are needed to ensure that the information collected is useful. If the methods are applied consistently between years, a valuable index of abundance can be developed, even if the estimates are not absolutely precise.

There are many important decisions that must be made when designing UVC surveys. When, where, how and why the surveys should be done are the key questions to be addressed. It is important, however, that before planning any aggregation survey, a preliminary exploratory dive be conducted at the site to provide basic information on the spatial extent of the aggregation, the depth range involved, and the water conditions, and to assess the order of magnitude of fish present and their responses to divers. Without this important information, it will be very difficult to design and plan a safe and scientifically meaningful survey.

Visual estimates are based on quantitative measures that either include the whole aggregation or can be expanded to include the entire aggregation (i.e. results from sub-areas are used as a basis from which to develop estimates that apply to the whole aggregation area). Most of these approaches fall into the category of "transect methods". The areal extent of the bottom area being surveyed must be known if measures of fish densities are needed, or if only some sub-areas can be sampled; this is why survey areas must often be mapped (see below). If surveys are to be repeatable, it is essential that a method is employed that allows the same area to be surveyed on each occasion. Distinct natural features on the bottom can be used for reference, or permanent floats or markers attached to the bottom. If natural features are used for reference, it is important that these be carefully documented (e.g. by mapping their positions), so that someone else can repeat a survey of the same area at a later date.

The problem of how to estimate fish numbers in an aggregation is tricky, with each species and site presenting its own set of challenges. At present, the best surveys have yielded only an approximation of actual numbers for aggregations numbering more than about 50 to 100 fish. The worst case is where fish are dense, distributed some distance from the bottom up into the water column, are moving constantly (as is the case for some acanthurids and lutjanids), are disturbed by human presence or are often hiding in the reef. In such cases, we would be fortunate to obtain a value that is within half or one-third the true number.

Measuring and mapping an aggregation site

If there is interest in assessing overall aggregation numbers but only sub-areas can be sampled (see above), the areal extent of the aggregation site must be measured. It is often most convenient to mark the edges of the site in advance, or at the time of the aggregation, using a marker that can be found later. This is particularly the case when an aggregation is of limited duration or fish are disturbed by diver activity within the aggregation site. The spatial extent of the aggregation can be measured later, based on the location of the markers, and an underwater survey done with compass and tape. If an accurate chart of the bottom is available, the edges of the aggregation can be plotted relative to known locations indicated on the map. Markers can take several forms: rocks painted different colours to represent different days, small lead fishing weights or short lines with floats. If the area of the aggregation is relatively large and surface floats are used, marker locations can be determined by using a global positioning system (GPS) receiver from a small boat. A rough estimate of the area can then be made, within the limits of GPS accuracy (see more on the application of GPS below). Markers can also be used to indicate the locations of specific fish for later analysis of spacing and density.

How to conduct an underwater survey

The size (i.e. length and width of each transect, with the width determined in part by visibility and general density of fish) and number of sampling units (i.e. total number of transects needed) must be determined. The effective transect width (i.e. the width across which fish numbers are being estimated) should then be determined, either visually (which requires experience) or by using markers previously placed on the substrate (see above). Transect length will be determined by the area or subsection of the aggregation to be surveyed, as well as other factors, such as depth and current. It would obviously be best to survey as large a proportion of an aggregation as possible.

Decisions must also be made regarding placement of transects within an aggregation. There may be few options, due to depth constraints, or as a result of the aggregation following a shelf edge contour or running along the walls of a reef channel or slope. Transects should be placed in areas that appear to be representative, but this may be very difficult to judge; their placement should be systematic. If the density clearly differs around the aggregation, then the best type of design is randomly stratified sampling (refer to Samoilys 1997; Samoilys and Carlos 2000; Colin et al. 2003). However, in this case, the strata must be identified. For large aggregations, the appropriate methodology must be used and this may require consulting the literature or obtaining advice from a biologist (Fig. 3).

Figure 3. Counting large numbers of densely packed aggregated fish can be very difficult and needs careful planning. This example is a Caribbean grouper.
Photo printed with the kind permission of Philippe Bush, Cayman Islands.

In general, considerable care is needed at each decision point when designing an aggregation monitoring programme, taking into account the remarkable aggregation density variability that can occur over time and among locations, even within a species. Every attempt must be made to design a method that is repeatable, representative and provides some indication of the precision of the resulting estimates, although total counts may not have measures of precision associated with them. If these requirements are not met, the data obtained may be of little value and the money and time spent getting them may be squandered. Attempts should also be made to evaluate the accuracy of the results by independent means (such as video) whenever possible.

New methods are being developed that will make fish counts and data analysis easier to perform. For example, Pat Colin has developed a method based on GPS technology using a popular line of GPS receivers (Garmin eTrex; see http://www.garmin.com/products/etrex/; this model has the necessary features to support the methodological approach used). A GPS receiver works quite well inside a plastic (e.g. PVC) housing that protects it from the elements. This allows the receiver to be used underwater, where it can record positions over time in any sort of marine survey, logging positions at a pre-programmed time interval. If the unit is attached to a float it can be towed by a diver (who must be on the surface) or a snorkeler to record the surveyor's swimming track. Likewise it can be attached to a current drifter and the track of the drifter can be downloaded from the unit after its recovery. The resolution of GPS-derived position data is about 2 m and the accuracy about 5–6 m. For further information on how to make or purchase a GPS unit housing, see newsletter No. 6 of the Society for the Conservation of Reef Fish Aggregations at www.scrfa.org or contact crrf@palaunet.com.

In some situations, such as where currents are strong, or where fish and divers are in close proximity, it may be preferable for the diver to hold a fixed position and do stationary counts (see Colin et al. 2003).

Sources of error in fish counts

There are many possible sources of error when assessing fish numbers underwater, even when a monitoring protocol has been properly and carefully designed. These include substrate complexity, fish behaviour, between-diver differences in fish counts, changes in fish numbers between and within days, and double-counting (i.e. counting the same fish twice). Preliminary work can help to establish what kind of errors may have to be considered (for more detail, see Colin et al. 2003).

When should monitoring be done?

Having decided why, what and how to survey, decisions must also be made regarding when surveys should be conducted. If aggregations typically occur at a new moon, for example, then monitoring activity should be concentrated during that period. The probable timing of an aggregation must first be determined, however, as a species at a particular aggregation site may sometimes shift the timing of its aggregation between moon phases. Monitoring should initially occur at different moon phases and during the typical non-spawning period to ensure that important information on spawning timing is not missed. Whenever the timing of aggregation is not well known, examination of the reproductive status of fish available in markets and discussion with fishers may provide additional information useful for planning monitoring activities (see the country reports available at www.scrfa.org or write to scrfa@hkucc.hku.hk for examples of an interview approach). Decisions must also be made regarding the time of day to monitor an aggregation, given that fish numbers can vary markedly at an aggregation site over the course of the day. If a species is being studied for the first time, the preliminary studies should involve regular and frequent surveys.

Summary

Before starting any monitoring programme, it is important to ask (and answer) the following questions and take into account a number of considerations. This will help in focusing on the appropriate methods and approaches to use.

Why?

What is the purpose of the survey? Must it be repeatable?

When?

When in the year, month and day should the surveys be conducted? Are non-aggregation surveys also needed for reference? Is information needed on aggregation seasonality throughout the region?

Where?

Should surveys be confined to the aggregation site? Should both aggregation and non-aggregation sites be surveyed (i.e. survey the fish during the non-aggregation season)? Should the entire site or only part of the site be surveyed? Which parts of the site should be surveyed — a core area or along randomly placed transects?

How?

A preliminary site survey is needed first, in order to determine the depth and spatial extent of the aggregation, the order of magnitude of fish numbers, the effects of divers on fish and fish hiding behaviour, and so forth. This information is critical for the proper design of subsequent surveys. Other important steps and considerations include:

- Map the aggregation area.
- Qualitatively assess the number of fish and any core groups or dense schools.
- Depending on the density of fish, divide the aggregation site into sections, grids or contiguous transects to cover entire site.
- If the fish are very dense or spread out, subsample the site based on strata (e.g. depth and habitat).
- If fish numbers are not too high or fish not overly dense (50–100 fish or up to 50 fish per 1000 m^2) then count all the fish unless they are spread over a very large area. This will give a total count.
- If there are distinct schools or core groups, sample these, map their location within the site to note any shifts in their location, and also sample fish densities between the core groups. If the core groups are very dense, sub-sample them.
- Make careful notes of the methodologies and protocols used so that others can later repeat the surveys.

Concluding comments

Carefully designed surveys are critical for detecting changes in the number of fish over time and to enable conservation and management decisions to be made based on that information. Conclusions drawn from the results of surveys must recognize the limits and constraints of the survey and of the sampling protocol. Most importantly, when designing any survey, ask yourself where, when and how the survey should be done and why it is being conducted in the first place.

The reasons for monitoring need to be carefully considered, and will strongly influence how monitoring can be conducted. Other important determinants of the monitoring approach include the species in question and local conditions (such as depth, current, ease of access to spawning aggregation sites, and budget). Where economically feasible, monitoring is important. In most cases, aggregations should be managed in order to ensure that the stock will persist in sufficient numbers to support ongoing fisheries.

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