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BIOLOGY AND FISHERY OF DOLPHINFISH AND RELATED SPECIES. *E. MASSUTÍ and B. MORALES-NIN (eds.)*

Fish Attraction Devices (FADs) and experimental designs*

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SUMMARY: There is widespread use of fish attraction devices (FADs) in commercial fisheries and research. Investigations on the utility of FADs to catch fishes, and factors influencing fishes associated with FADs, require careful consideration of experimental designs. The development of appropriate models, from observations and the literature, should be developed before hypotheses can be tested with robust sampling designs. Robust sampling designs may only be possible if investigators have some role in the planning stage of deploying FADs. If the objective of the study is to determine the influence of FADs on assemblages of fishes, then experimenters need to consider that a 'FAD-effect' (=impact) cannot be demonstrated without controls. Some preliminary studies may be required to determine the spatial extent of a FAD-effect before suitable sites can be chosen for controls. Other controls may also be necessary, depending on the method used to estimate numbers of fishes (e.g. controls for disturbance). Recent advances in sampling designs that are applicable to impact studies are discussed. Beyond-BACI (Before After Control Impact) and MBACI (Multiple BACI) designs are recommended because they cater for temporal and spatial variation in the abundance of organisms, which is generally great for pelagic fishes. The utility of orthogonal sampling designs is emphasised as a means of elucidating the influence of multiple factors and, importantly, interactions between them. Further, nested analyses are suggested to deal with multiple temporal and/or spatial time scales in sampling designs. The independence of replicate FADs should also be considered. Problems of independence include: FADs that are connected, thus providing potential routes of movement of associated fishes; temporal dependence where the number of fish at a time influences the number at the next time due to fish becoming residents; and the fact that the proximity of other FADs may influence numbers of fishes. Solutions to these problems are suggested. The recommendations in this paper are relevant to investigations on pelagic fish of all sizes, with and without FADs.

Key words: experiments, FADs, impact, sampling designs.

INTRODUCTION

Pelagic fishes, including dolphinfish (*Coryphaena hippurus* and *Coryphaena equiselis*), have been observed around free floating rafts (Heyerdahl, 1950; Yabe and Mori, 1950; Gooding and Magnuson, 1969; Dooley, 1972) and have been the basis for fisheries around moored fish attraction devices (hereafter FADs) in many parts of the world (Kojima, 1956; Galea, 1961; Bombace, 1989 Massutí and Morales-Nin, 1991; Higashi, 1994). There is no question that fish are found around these devices. There are many reasons why fishers and fisheries have used FADs, or are interested in their potential. The perceived positive reasons why FADs may improve fisheries range from simple concepts of increasing catches of pelagic fish within an area to providing sustainable fisheries (Table 1). FADs may also provide research workers with a tool for collecting larval and juvenile fishes that are difficult to collect using conventional

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TABLE 1. – Examples of perceived advantages and disadvantages of FADs that have been proposed for pelagic and benthic fishes as adults and in some cases for early life history stages (sources include: Bohnsack and Sutherland, 1985; Rountree, 1990; Kingsford, 1993). These models can be the basis of hypotheses that can be tested in the field. The hypotheses that are tested should, ideally, be determined before FADs are deployed in the field.

Advantages
(1) Target for fishing (concentrate vagrants)
(2) Increase catches of fish within an area
(3) Increase biomass (numbers and growth) by providing more habitat that is attractive for fishes
(4) Facilitate greater recruitment to an area
(5) Increase and sustain diversity of fishes in an area
(6) Transform non-productive areas for fishing into productive areas
Disadvantages
(1) Aggregation can make a stock that is usually dispersed very vulnerable
(2) Change routes of migration
(3) Compromise other fisheries in space and time
(4) FADs result in a redistribution, not an increase in numbers of fishes
(5) Compromise recruitment to natural sites
(6) FADs are litter and/or shipping hazard

methods (Hunter and Mitchell, 1967; Kingsford and Choat, 1985; Kingsford, 1992) and provide measures of recruitment to pelagic fisheries. In addition to potential positive attributes, there are also negatives that include making the stock vulnerable to over-exploitation (through concentration in small areas), altering routes of migration and increasing rates of predation on the early life history stages of other commercial fishes. Some potential positive and negative attributes of FADs have originated from investigators working on benthic FADs, but they are also applicable to pelagic fishes.

The purported positive or negative attributes of FADs and the processes influencing associations (Table 2) are essentially models of how the system works (*sensu* Underwood, 1990, 1997). It is not difficult to think of multiple reasons why FADs will be of benefit to a fishery and, perhaps with less enthusiasm, negative points. The challenge is to provide statistically robust information that is unambiguous and of relevance to the fishery.

The purpose of this discussion paper is to revisit aspects of sampling theory that are relevant to the research on FADs. It should be remembered that the ability to isolate factors or combinations of factors that influence fishes around FADs depends on the clear articulation of a hypothesis(es) and a sampling design that results in a test that is unconfounded. In short, the general objectives of sampling programs, and specific hypotheses that result from that program, should determine where and when FADs are deployed. The ability to identify patterns and determine the processes that influence the patterns are often compromised because scientists are not sufficiently involved at the planning stage of a sampling program. It is common for FADs to be deployed with little thought of the hypotheses that need to be tested (Bohnsack and Sutherland, 1985; benthic FADs). There is merit in making the best of a bad situation, but active lobbying at the planning stage might avoid less than ideal situations.

TABLE 2. – Factors that may influence numbers of fish around FADs. These models can be the basis of hypotheses that can be tested in the field. The hypotheses that are tested should be determined before FADs are deployed in the field. Many of these hypotheses are relevant to both juvenile and adult fishes.

Factor	Source (examples)
(1) Availability of food	Kingsford and Choat, 1985; Buckley and Miller, 1994
(2) Availability of juvenile fish	Gooding and Magnuson, 1967; Rountree, 1990
(3) Presence of conspecifics (spawning, cannabalism, density effects)	Rountree, 1990
(4) Presence of other species (competition, predation, potential prey)	Greenblatt, 1979; Rountree, 1990
(5) Availablity and nature of shelter (FAD design)	Rountree, 1989, 1990; Kingsford, 1992
(6) Substrate for undergoing a behavioural change	Hunter and Mitchell, 1967
(7) Day versus night	Feigenbaum *et al.*, 1989
(8) Intra- and interspecific competition	
(9) Predation (by residents and vagrants)	Buckley and Miller, 1994
(10) Larval/juvenile drift to 'suitable' areas	
(11) Disturbance, natural (e.g. storms) and anthropogenic (e.g. boat noise)	Rountree, 1990; Bell and Hall, 1994
(12) Proximity to the shore	Friedlander *et al.*, 1994; Kleiber and Hampton, 1994
(13) Location and time (due to variation in larval supply and movements of fishes)	
(14) Water quality and visibility	
(15) Design of FADs	Hunter and Mitchell, 1968; Kilma and Wickman, 1971
(16) Size of FAD	Kingsford and Choat, 1985; Rountree, 1989; Kingsford, 1992
(17) Clusters of FADs	Wickham *et al.*, 1973
(18) Soak time of FADs	Hunter and Mitchell, 1968
(19) Combination of pelagic and benthic FADs	Beets, 1989; Rountree, 1990

It is emphasised that researchers should take note of active debates in other areas of environmental sciences -in particular the theory and practise of impact studies- because useful lessons can be gained on appropriate temporal and spatial scales of sampling as well as controls (review: Schmitt and Osenberg, 1996). There is a tendency to view potential positive influences of FADs as not being impacts. FADs do constitute an impact, it is just that the measures of 'after' impact (i.e. addition of FADs to the pelagic environment) are measured as a positive result. The specific aims of the review are as follows: to discuss impact studies and their relevance to research on FADs; to emphasise the importance of controls; to describe sources of temporal and spatial variation in abundance; to discuss methods for dealing with spatial and temporal variation; and to discuss problems concerning the independence of replicate FADs in sampling designs and methods for determining appropriate numbers of replicate FADs.

REVIEW

Some lessons from impact studies

FADs do constitute an impact and therefore sampling designs should be viewed in this way. There are some fundamental requirements for an impact study that were articulated by Green (1979) in that sampling should be done before and after the impact (i.e. before and after FADs are deployed). This approach has been incorporated in some studies of FADs (Buckley and Miller, 1994). The concept of BACI designs (Before, After, Control, Impact) has advanced considerably in the 1990s (Kingsford and Battershill, 1998a). Temporal variation in abundance, diversity and other variables can be great at a site, particularly for pelagic fishes, as can spatial variation in patterns within and among sites. This generalisation is true regardless of the status of sites as impact or controls. Based on this recognition, therefore, a fundamental requirement of acceptable impact studies are comparisons of impact site(s) with multiple control sites. More than one control site allows a potential impact to be detected that is not confounded by natural spatial variation that is not related to an impact (Fig. 1). In cases where the impact of one set of FADs is measured, Beyond-BACI designs are a sensible option (Underwood, 1994). For example, a single site with FADs may be compared with more than one control site, and such a design would incorporate multiple times before and after the deployment of FADs (Fig. 2). In many cases the objective of a study is to measure the influence of multiple FADs or groups of FADs and MBACI designs (Multiple Before After Control Impact; Keough and Mapstone, 1995) are ideal for

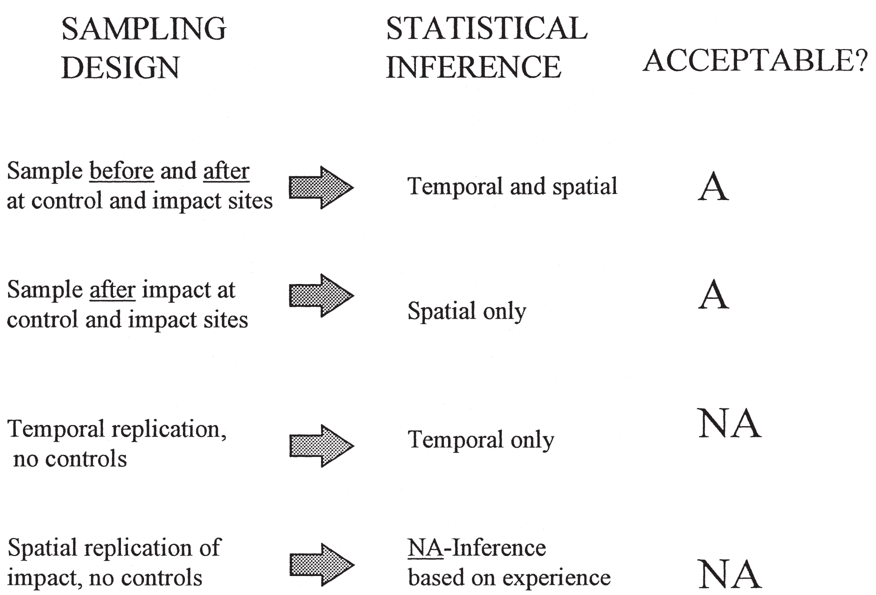

FIG. 1. – The nature of impact studies. The essential components of sampling designs are indicated and the statistical inference that can be made if the null-hypothesis is rejected. Acceptable (A) and unacceptable (NA) sampling designs are indicated. For acceptable designs the results are most conclusive and have greater ecological reality (based on natural temporal variation) if sampling is done at multiple times.

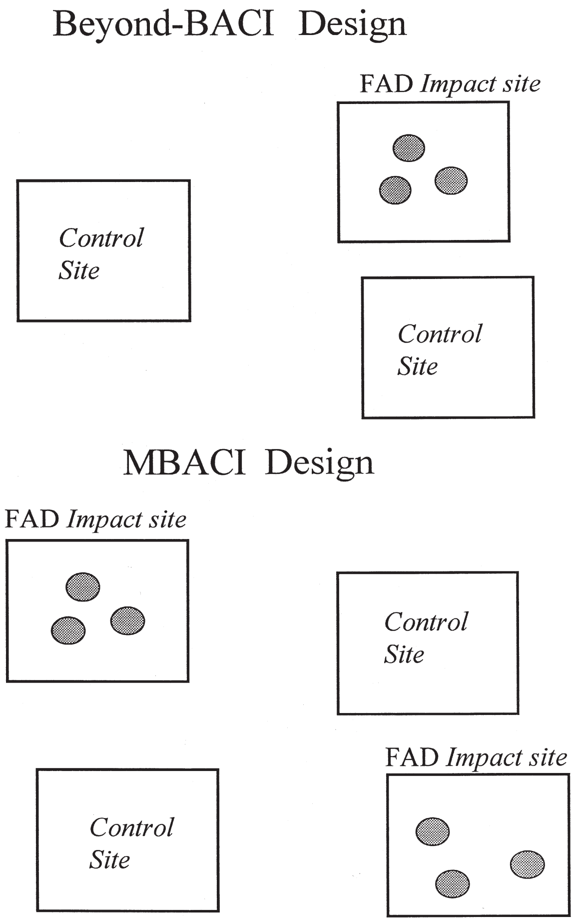

FIG. 2. – A schematic diagram of Beyond-BACI (single site of impact) and MBACI (multiple sites of impact) sampling designs (BACI=Before, After, Control, Impact). Each of these designs has more than 2 control sites (=reference sites). Circles within impact sites indicate replicate FADs; three replicate sets of samples would also be taken from each control site. Strongest statistical inference of an impact (i.e. 'FAD-effect') would come from sampling multiple times before and after the deployment of FADs. For a more detailed explanation of these designs see Kingsford and Battershill (1998b).

this type of problem. The principles of MBACI designs are similar to Beyond BACI, but there is more than one impact site (Fig. 2).

Importance of controls

An impact cannot be demonstrated without a comparison of impact sites and controls (= references sites without FADs). The lack of controls in the experimental designs of many early studies on the use of FADs was pointed out by Bohnsack and Sutherland (1985) for artificial reefs. There are many contemporary investigations in which comparisons have been made between catches around artificial and natural FADs and open water (e.g. Feigenbaum *et al.*, 1989; Fabi and Fiorentini, 1994). The importance of controls is emphasised for studies on large pelagic species as well as larval and pelagic juvenile forms. For example, Friedlander *et al.*, (1994) found greater numbers of tuna around FADs at the surface than in open water, while fishes in mid-water column were just as abundant in open water as around FADs. Kingsford (1992) found large numbers of many types of larvae around natural attraction devices (drifting algae), but found that some of them were just as abundant in open water controls. Druce and Kingsford (1995) found that some larvae were less abundant around some FADs than in open water and suggested that predation by the assemblage associated with FADs may be responsible for this pattern. If controls had not been used in any of these studies, all that could be said is that fish are (or are not) caught around FADs. In addition, inference on the magnitude of attraction (or lack of it) would not have been justified.

The ways in which fishes are sampled for estimates of abundance may require other types of controls. Relevant controls will often vary with the type of gear that is used to sample around FADs and to obtain accurate estimates of abundance in open water. Methods vary greatly and may include: counts from the air; snorkelling or SCUBA; seine nets (Hunter and Mitchell, 1968); and lure strikes and catches (Buckley and Miller, 1994). It is possible, for example, that when fishes are disturbed in open water by an approaching net they scatter and will only be caught when they attempt to shelter close to an object. Kingsford and Choat (1985) and Kingsford (1992) used a small purse seine net to sample fish around natural and experimental FADs and had three types of controls in open water as follows: (1) seines in open water; (2) seines around FADs (pieces of algae) that were tossed in the sea and seined immediately; and (3) ichthyoplankton tows with a conventional ichthyoplankton net.

The distance from FADs at which fishes are influenced by them is also of concern in sampling designs and information of this type may need to be the objective of specific designs. Buckley and Miller (1994) considered fish to be associated with FADs if they were caught within 1.6 kilometres of FADs. Cillaurren (1994) demonstrated that catches and takes on lures were highest within 0.3 kilometres of FADs. More direct evidence was provided in a tagging study by Ibrahim *et al.* (1990), in which tagged fish of a variety of taxa were released at different distances from FADs. They concluded that the effective range of detection was 180 m. In a review on

TABLE 3. – Sources of temporal and spatial variation in the abundance of fishes around FADs. Sources include: Stephan and Lindquist, 1989; Holland *et al.*, 1990; Rountree, 1990; Kingsford, 1992; Bell and Hall, 1994; Buckley and Miller, 1994. Physical environment refers to variation in the physical environment that may influence the ecology of fishes. Biology refers to aspects of biology that are influenced by variation in the physical environment and variation in abundance due to fisheries.

Temporal Variation *Temporal Scale*	*Physical Environment*	*Biology*
Diel	Light dark	Migrations, feeding, detection of FAD using visual cues
Time of day	Light	Feeding, satiation, behaviour of prey
Weeks	Storms, currents	Movement, predation, fishery, recruitment
Months	Storms, currents, temperature, upwelling	Movement, predation, fishery, recruitment
Seasons	Storms, currents, temperature, upwelling	Movement, predation, fishery, recruitment, reproduction
Years	Physical forcing (e.g. El Nino),	Movement, predation, fishery, recruitment, reproduction
>10 years	Physical forcing (e.g. El Nino), climate change	Movement, predation, fishery, recruitment, reproduction

Spatial Variation *Spatial scale*	*Plane*	*Physical environmental and biology*
mms-1m (Microscale)	Horizontal Vertical	Behaviour of larvae
0-999m (Fine scale)	Horizontal Vertical	Behaviour (migrations, presence of conspecifics, other members of the assemblage, including predators and prey)
1-100km (Coarse scale)	Horizontal Vertical	Behaviour (migrations, presence of conspecifics, other members of the assemblage, including predators and prey), oceanography (frontal regions), patterns of recruitment
100-1000km (Mesoscale)	Horizontal	Behaviour (migrations and reproduction) oceanography (minor currents and eddies)
1000-3000km (Macroscale)	Horizontal	Behaviour (migrations, reproduction), oceanography (major circulations, currents), patterns of recruitment, patterns of abundance of prey, physiological tolerance
3000km+ (Megascale)	Horizontal	Behaviour (migrations, reproduction), oceanography (major circulations, currents), patterns of abundance of prey, physiological tolerance

artificial reefs, Bohnsack and Sutherland (1985) commented that the effective boundary for midwater and surface fishes is 0.2-0.3 km, but that this may be assymmetrical based on the position of fishes in relation to currents. The area of influence, or spatial extent of impact, needs to be considered for the placement of controls. For some FADs and sizes of fish the area of influence may be on a scale of metres. Druce and Kingsford (1995) found significant differences in numbers of small fishes between natural and experimental FADs and open water controls that were only separated by tens of metres.

Although controls are included in many sampling designs that address hypotheses concerning FADs, there is still little consideration for allocation of sampling effort at other levels of designs, particularly in space and time.

Sources of spatial and temporal variation

There is great temporal and spatial variation in the distribution and abundance of most marine organisms (Kingsford and Battershill, 1998b) and this is particularly true for pelagic fishes such as dolphinfish (e.g. Table 3). For example, there can be great variation in the abundance of pelagic fishes and their larvae among seasons within a year and between years (Rountree, 1990; Kingsford, 1992). This variation may relate to spawning, recruitment and routes of migration. On shorter temporal scales fish may undergo diel vertical migrations and travel tens of kilometres within a day (Holland *et al.,* 1990). In addition, catchability may even change with time of day (Crook, 1987). Variation in space may be great and range from metres to thousands of kilometres. Patterns of reproduction, the distribution of food and oceanography may influence spatial patterns at scales over 100 km. On smaller spatial scales oceanography can be important, as well as proximity to shore (Kuwahara *et al.,* 1982) and predation. Predation rates can be high on small scombrids and spatial differences in predators may influence catches around FADs (e.g. tuna ~90cm; Buckley and Miller, 1994). The challenge is to cater for this variation in ways that: (i) increase the power of generality of our findings; and (ii) allow comparisons to be made among experimental treatments in such a way that the comparisons are not confounded or obscured by temporal and spatial variation. Investigators should consider multiple sources of variation in sampling designs, even if it is to justify that conditions are similar.

Dealing with variation at multiple temporal and spatial scales

Trust your biological intuition on variation that should be catered for in sampling designs. In general the investigator has some model of how the system works based on local experience and the literature. Invariably this will involve stratification in space (e.g. by depth, location, distance from shore, oceanography), time (e.g. years, seasons, months), different types of gear designs (e.g. Hair *et al.,* 1994) or manipulations of the fauna (e.g. with and without small invertebrate food). There are, however, a few ground rules that are worth reminding ourselves of. The rule of thumb is that there should be replication within each level (Factor) of a sampling design. For example, to demonstrate differences among years you need replication within a year; if you are trying to demonstrate differences among months you need to sample times within months; and if you are trying to demonstrate differences with respect to time of the day, then sampling should be done on multiple days to determine the generality of the patterns (Kingsford, 1998).

The spatial arrangement of FADs is often poor in sampling designs and this leads to low power in statistical tests, 'pseudoreplication' (*sensu* Hurlbert, 1984) and a poor ability to generalise about the findings. For example, you cannot argue that there are great differences in the abundance of a species around single FADs, one located offshore and the other inshore, and attempt to relate to distance from shore. It is possible that this variation in abundance may be found among replicate sites at the same distance from shore. Planning at the deployment stage of FADs, and carefully designed orthogonal and mixed model designs can avoid some of these problems (Underwood, 1997). The benefits of these designs are that they can provide tests for multiple sources of variation in time and space in the same analysis. Importantly, they cater for interaction between factors. For example, it is highly likely that fish may be more abundant nearshore than offshore, but the magnitude of difference may vary according to the location at which comparisons are made. This will result in a significant interaction between distance and location (Table 4). The design presented in Table 4 would be appropriate if the objective were to determine the impact of FADs and determine whether that influence was consistent nearshore and offshore and at multiple locations. In this case, investigators could only make spatial inferences about the impact of FADs. The design could be improved by adding a before/after factor and multiple times of sampling both before and after the FADs were added to the area (as for an MBACI design; Keough and Mapstone, 1995).

TABLE 4. – Example of a sampling design that allows catches at multiple FADs located nearshore and offshore to be analysed with Analysis of Variance. The factors Control/Impact and Distance were treated as fixed factors and location as random (*sensu* Underwood, 1997; Kingsford, 1998). It can be seen that that power of the test will increase for the most important factors (Control/Impact and Distance) as the number of locations are increased. The number of replicates (n) must be two or more. See Underwood (1997) for the calculations of degrees of freedom and F-statistics; C/I = Control/Impact, D = distance, Loc = Location.

Source of Variation	Treatments	Degrees of freedom	Denominator Mean Square for F-statistics
Control/Impact = a	Control, Impacts	(a-1)	C/IxLoc
Distance = b	Nearshore, offshore	(b-1)	DxLoc
Location = c	Loc 1 to c	(c-1)	Residual
C/IxD		(a-1) (b-1)	C/IxDxLoc
C/IxLoc		(a-1) (c-1)	Residual
DxLoc		(b-1) (c-1)	Residual
C/IxDxLoc		(a-1) (b-1)(c-1)	Residual
Residual	n=2 to n	abc(n-1)	

Multivariate methods can be used to analyse the composition of assemblages and have been used extensively in studies of impacts (e.g. Clarke, 1993). Multivariate methods cannot, however, cater for all of the complex interactions in multifactorial tests that are provided by ANOVA.

Independence

There are a number of potential problems concerning the independence of FADs, which may include:

(i) FADs of different treatments (e.g. design, depth) that are connected by lines;

(ii) the proximity of FADs to one another;

(iii) fish that are counted at time 1 have a great influence on what is counted at time 2, especially for fishes that set up residence.

Connected FADs are not independent. For example, pelagic FADs that are connected to benthic FADs may increase numbers of fishes on the benthic set (e.g. Rountree, 1990). Similarly, if FADs are set at different depths, they should be on separate lines. If they are spaced along the same line they can provide immigrants with a route (line of perceived shelter) to the next FAD.

If FADs are relatively close together they may attract even more fishes than the sum of the same number of well separated FADs. Specific hypotheses may be tested on the collective attributes of FADs. Kennelly and Craig (1989) found that catches of spanner crabs were higher in traps set close together than in traps that were well separated. Similarly, Wickham *et al*. (1973) found a higher abundance of pelagic fishes in clusters of FADs. Furthermore, some species were collected in clusters of FADs that were rare or absent from isolated FADs (e.g. *Coryphaena*).

FADs are unlikely to be independent among times, especially in multi-species comparisons. The problem is that some fish set up residency, particularly if they are more likely to stay in the presence of other species or conspecifics. For example, Hunter and Mitchell (1968) found that some tagged fishes stayed near FADs for 8 (*Lobotes pacificus*; Lobotidae) to 32 days (*Sectator ocyrus*; Kyphosidae). This problem is also relevant to pelagic fish such as *Coryphaena,* as tagged individuals may stay around a single FAD for hours to days (Kingsford and DeFries, 1999). Residency of this type may be more likely the longer FADs have been in the water. For example, Hunter and Mitchell (1968) found that FADs were more likely to be colonised by large pelagics if small fish are present. Non-independence violates the assumptions of some forms of analyses (e.g. ANOVA, Underwood, 1997).

Problems of independence may be resolved by sampling different FADs at each time for each treatment. In practice, however, this is very difficult and/or too expensive to do. This problem has been dealt with in a number of ways:

(i) by using repeated measures analyses (Green, 1993; Keough and Mapstone, 1995), although this approach cannot deal with issues such as connected FADs;

(ii) excluding time from analyses, although this is not an option for many hypotheses;

(iii) by basing sampling intervals on the assumptions that pelagic fish are moving about so much that residency is unlikely (Holland *et al.,* 1990; Mathews and Deguara, 1994; Kingsford and DeFries, 1999), so problems of independence are not considered to be an issue for comparisons among times; the tagging of fish may assist in determining residence times (see Parker *et al.*, 1990).

(iv) by destructive sampling (i.e. all fish removed; e.g. Hair *et al.,* 1994); but beware of problems of FADs that have been in the field for different periods of times.

How many replicates?

High variances among replicate FADs and potentially in open water pose a problem for analyses. Historically this was dealt with by pooling replicates and ignoring variation. This option, however, is a poor one because it loses information on spatial variation in the abundance of fishes and makes the data unsuitable for many parametric statistics.

Estimates of precision can be determined in pilot studies using well established methods of comparing the standard error as a percentage of the mean for different numbers of replicate sampling units, in this case FADs (Kingsford, 1998). A problem with FADs, however, is that pilot studies have to be very comprehensive if they are to adequately cater for given natural variation in abundance of fishes in space and time.

In some cases, high variances as a result of very large aggregations of fish associating with a single FAD are unavoidable. In these cases resolution of patterns among treatments may only be obtained by repeating experiments multiple times and looking for consistency of patterns.

Units of measure should also be considered at the sampling design stage when analyses are considered a-priori. Are data to be analysed as number, size of fishes (Buckey *et al.,* 1989), biomass or diversity? If diversity is the issue, beware of measures of diversity that are not accompanied by measures of abundance (Holbrook *et al.,* 1994).

Demonic intrusions

In some parts of the world it is highly likely that natural drifting objects, such as drift algae (Kingsford, 1993, 1995; Davenport and Rees, 1993; Ingolfsson, 1995), and man-made objects (e.g. plastic bags; Lecke-Mitchell and Mullin, 1992) may intrude into a study area and potentially confound simple comparisons among artificial FADs and open water controls. Some options in this situation are as follows:

(1) set up a sampling design that measures densities of other drifting objects;

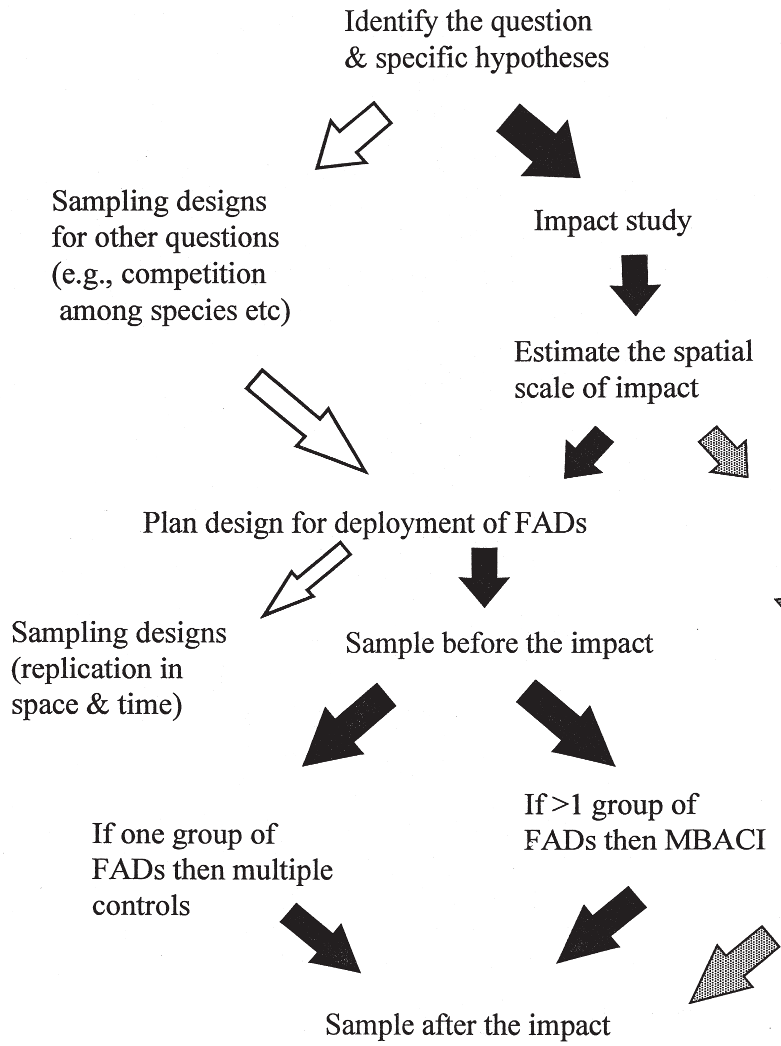

FIG. 3. – The sequence of events that should go into the planning and field activities of a study on FADs. Emphasis is given to determining the impact of FADs on pelagic fishes (dark arrows). In many situations it is not possible to sample before the impact, because the FADs have already been deployed (stippled arrows), in these cases asymmetrical (Glasby, 1997) or orthogonal designs with controls would be best. There are many other types of questions that may be addressed about the fishes associated with FADs that may require different sampling designs (white arrows). I have recommended that these designs be replicated in space and perhaps time to strengthen the generality of the conclusions. Note that MBACI (Multiple Before After Control Impact) has multiple controls.

(2) take the opportunity to sample other drift material and compare it to FADs and open water controls;

(3) note the presence of large quantities of other drift material if it coincides with the time of sampling FADs.

CONCLUSIONS

Determining the influence of FADs on species and assemblages of pelagic fishes can be complex. This is partly because of the high levels of spatial and temporal variation in abundance of these fishes, which is typical of highly mobile species. Difficulties with sampling designs are sometimes encountered when investigators do not recognise that they are doing an impact study. The essence of good sampling designs is a sequence of events that encompass identifying the general problem (e.g. what influence do FADs have on the abundance of fishes?) and articulating specific hypotheses to planning the deployment of FADs and sampling FADs and controls correctly in space and time (Fig. 3). FADs are sampled for many reasons other than just detecting impacts, but the principles of careful planning and adequate replication in time and space will greatly increase the investigators' ability to make general statements about the results.

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