Dispersal Rates of Commercially Important Coral Reef Fishes: What do Tagging Studies Tell Us About Potential Emigration from Marine Fisheries Reserves

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ABSTRACT

Marine Fisheries Reserves (MFRs) should be integral to the management of tropical reef fisheries. Nevertheless, many questions regarding MFR design and function have not been fully answered. Paramount to the success of any MFR is the rate of movement of juvenile and adult fishes, as this will determine the rate of export of fish from an MFR and hence the degree of conservation and/or fishery enhancement in adjacent areas. Mark and recapture studies offer a potentially definitive way to estimate dispersal rates. Most past mark and recapture studies are of limited use in estimating dispersal rates. Deficiencies include the following: small sample size, limited spatial or temporal scale of recapture effort, confounding effects of habitat requirements, limited size range of fish marked, and insufficient data reporting. Reports of displacement distances over time do give some idea of the potential for dispersal, but without an understanding of the underlying processes controlling fish movement, generalizations derived from isolated studies could lead to significant over- or underestimation of dispersal rate.

KEY WORDS: Fishery Reserve, movement, tagging, reef fish

INTRODUCTION

Interest in using marine fisheries reserves (MFRs) as management tools has been increasing in recent years. This has been particularly true for coral reef fisheries, where the costs of traditional management approaches are high relative to the value of the fisheries, the communities and fisheries are complex, and the degree of habitat dependence is high. Nevertheless, many questions regarding MFR design and function have not been fully answered.

The degree of movement expected of individual fish is the most important aspect affecting the biological success of any MFR. Two aspects of MFR function are affected by movement, and these constitute to some degree opposing goals: protection and seeding. Movement affects the degree of protection a reserve can potentially offer, regardless if the goal of the protection is to enhance growth, enhance reproduction or genetic diversity. If movement is large relative to MFR size, emigration will be to high to afford adequate protection.

Objectives for establishing a seeding role of an MFR are to compensate for lost production due to area closure, enhance overall production within the system, and to repopulate surrounding, overfished areas. Seeding requires emigrating from the reserve area, but this cannot be done at the expense of the production of individuals to seed (i.e., protection).

One of the principal techniques available to study the movement of individual or groups of fish tagging. This technique potentially gives information on the displacement of fish over time by fish size, location and time at liberty, but it does not make any inference about when fish move within this period nor the path taken between marking and recapture. In this study, past studies using mark-recapture techniques are reviewed relative to their ability to infer potential movement and hence emigration rates from marine reserves.

METHODS

A total of 16 reports covering 10 separate mark-recapture programs were reviewed (Table 1). For each study, the temporal and spatial scales of experimental work and the limitations to these were determined, particularly with respect size, behavior, habitat and sampling effort. For species with sufficient returns, attempts were made to generate dispersal distribution patterns, i.e., frequency distributions of displacement distances. Rates of dispersal (relative to distance) were taken as the slope of the above frequency distributions (using the natural log of frequency). The success or failures of these results were assessed to see if similarities emerged.

RESULTS AND DISCUSSION

Sampling Effort

The spatial and temporal scales of study were largely determined range and intensity of sampling effort. The studies of Bardach (1958), Springer and McErlean (1962), Randall (1961, 1963) and Friedlander *et al.* (1995) were conducted on small spatial scales, from 100 to 1000 m. Unfortunately, tagging techniques cannot differentiate, without additional data, between possible causes of low recapture (e.g., low sampling efficiency, mortality, emigration). With the exception of the latter study, the scale of study was limited because most of the sampling for recapture was conducted by the authors. Thus, emigration outside of the study area would not be recorded. Also, these studies were generally of short duration (≤ 1 year) and times at liberty were generally much shorter. Thus, while these studies are valuable for looking at short term habitat use and daily random or foraging movements, they are not useful for the longer term and larger scale data needed to assess potential emigration.

Table 1. Mark-recapture studies of reef-fish movement

Location	Study
Bermuda	Bardach, 1958
Florida	Springer & McErlean, 1962 Ingle, Hutton and Topp, 1962 Topp, 1963 Beaumariage, 1964 Beaumariage and Wittich, 1966 Moe, Beaumariage & Topp ,1970 Moe, 1966 Moe, 1967 Wilson & Burns, 1996
Australia	Beinssen , 1989
Hawaii	Holland, Petersen, Lowe and Wetherbee 1993 Holland, Lowe and Wetherbee, 1996 Friedlander, DeFelice, Parrish and Frederick, 1995
Virgin Islands	Randall, 1961 Randall, 1963

Size Range of Fish

All studies are limited by the smallest size at which individuals may be tagged without undue mortality. Quite often, except for species with large adult sizes (e.g. red grouper, red snapper), this means that juveniles will not be studied. This precludes the ability to study dispersal due to ontogenetic migrations, especially those from nursery areas to adult habitats.

Equally important is the possibility that movement will be somehow proportional to size. This is clearly evident in the movement of red grouper in studies conducted off Florida's west coast. Large juveniles stayed resident over long periods of time, but still larger adults were capable of very long migrations; in one study (Wilson and Burns, 1996) up to 16% of the adults moved at least 25 km, with maximum recorded displacement of 100 km. However, size of individuals tagged (or recaptured) is often randomly determined or selective to a narrow size range. With typically few individuals recaptured over a broad size range, size dependent movements will not be discernable.

Time at Liberty

Distance moved should to some degree depend on time at liberty. Nevertheless, in most studies it is difficult to factor out this effect. Most studies are dominated by recaptures occurring shortly after tagging (≤ 1 month). Inclusion of these returns biases the results toward an underestimation of movement potential, while elimination often reduces sample sizes to meaningless levels. Nevertheless, large displacements over short periods (e.g. 155 km in 12 days for the blue runner, *Caranx fuses*; Beaumariage 1964) or short displacements over long periods (e.g. no movement after 1,131 days for a 262-mm FL white grunt, *Haemulon plumieri*; (Moe 1967) may be indicative of general dispersal capabilities.

Habitat Characteristics

The movement of many species appears to be related to the type of habitat available and its distribution. Thus, knowledge of habitat use is important for interpreting tagging data. and this can occur on a variety of scales. For example, Holland *et al.* (1996) studied the dispersal of the blue trevally (*Caranx melampygus*) tagged in Kaneohe Bay, Oahu. Much of the sampling effort came from the investigators themselves, and must of the recaptures came from near their sampling sites. Nevertheless, there was substantial commercial and recreational fishing around the island to determine that at least fishes were leaving the bay and traveling distances up to 72 km (Figure 1). However, Kaneohe Bay is a unique habitat, being the only bay of its kind on the island of Oahu, and potential dispersal may have been restricted by this singular distribution of habitat. Similarly, Friedlander *et al.* (1995) studied movements of *Lutjanus kasmira* in Hanalei Bay on Kauai. No recaptures were recorded outside the Bay, despite the existence of significant recreational fishing, thus indicating limited dispersal. But again, Hanalei Bay is the only such bay on Kauai.

An important question regarding emigration from MRFs is whether fish will cross suboptimal habitat. For example, in the short-term study of Beinssen (1989) at Boult Reef, 10% of the coral trout (*Plectropomus leopardus*) were found to disperse greater that 2 km on a reef only 5 km long. This indicates substantial dispersal around this reef where habitat is continuous, but would the results be similar if the reef were not continuous? No recaptures were ever recorded away from the reef. Bardach (1958) reported that fishes resident in specific areas on 100-m diameter patch reefs were incapable of homing back to their reef when displaced to a similar reef 100 m away, while those species that roamed over the entire range of their resident reef (over a period of weeks) showed a strong homing ability when similarly displaced.

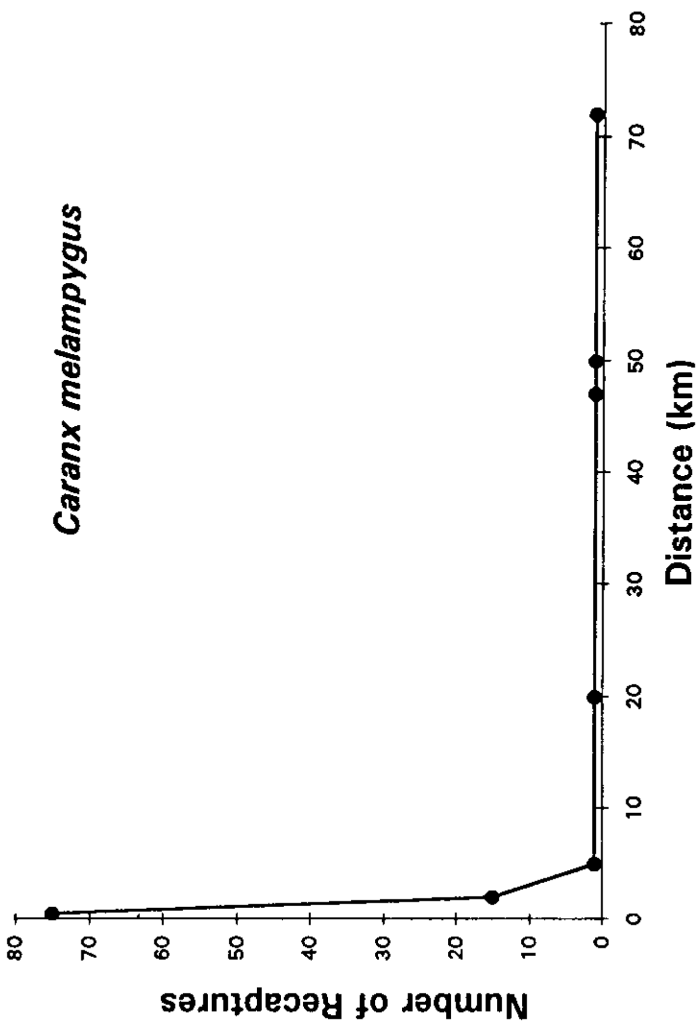

Figure 1. Number of recaptures versus distance traveled for the blue trevally (*Caranx malampygus*) regardless of time at liberty. Data from Holland *et al.* (1996)

A question of scale?

The results of tagging studies usually cannot be viewed outside the context of the area studied and the level of sampling effort. Thus it is difficult to extrapolate the results of one study to another area that may differ aspects of habitat type and distribution, or if the questions of relevance were not addressed by the spatial or temporal scales of the reference study. For example, Holland et al., (1996) argues that, based on their results, small reserves would still offer protection, even for species thought to be wide ranging, such as the blue trevally, where almost all were found within 1 km of the site of release. Randall (1961) found a similar pattern of distribution of yellowtail snapper, *Ocyurus chrysurus* (Figure 2), with almost all individuals found within 1 km of the site of release. However, Randall consider his low rate of capture of this species (using traps!) to result from significant emigration from his study area. In support of Randall's conclusion are the results reported by Beaumariage (1964). Only two individuals were recaptured, but each had travelled a long distance (155 and 92 km). The dispersal patterns from these two studies are quite different.

To exemplify the effect of the scale of study on the resulting pattern of dispersal and hence prediction of emigration potential, the dispersal rate for white grunt is plotted in Figure 3 for three studies (Springer and McErlean, 1962, Randall, 1961, 1963; Moe, 1966). In Figure 3, rate of dispersal is indicated by the slope of the line. The figure shows that the smaller the spatial scale of the study (250 m, 1 km, 20 km, respectively), the steeper the slope of the line and hence the lower the expectation for emigration.

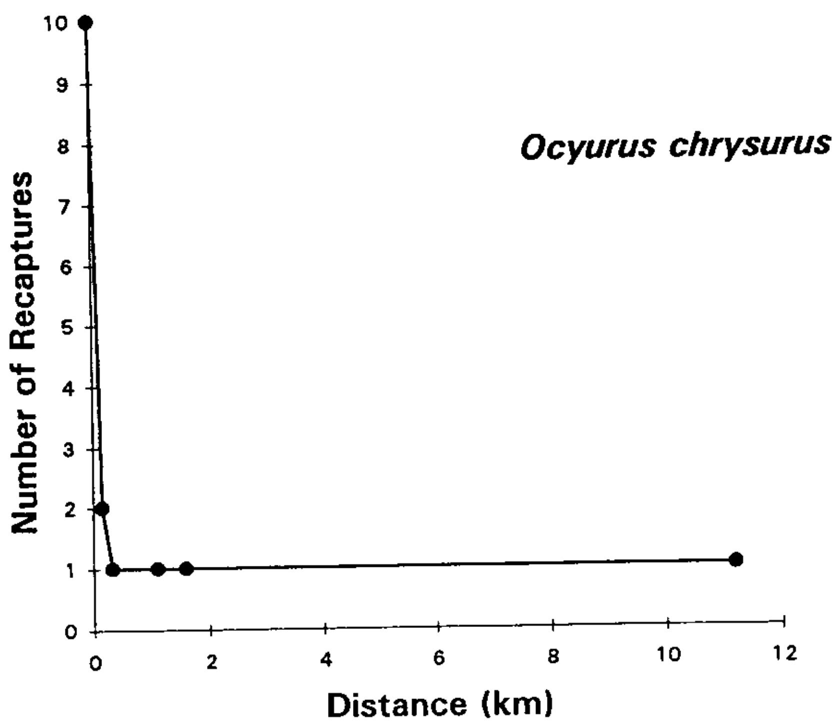

Figure 2. Number of recaptures versus distance traveled for yellowtail snapper (*Ocyurus chrysurus*) regardless of time at liberty. Data from Randall (1961).

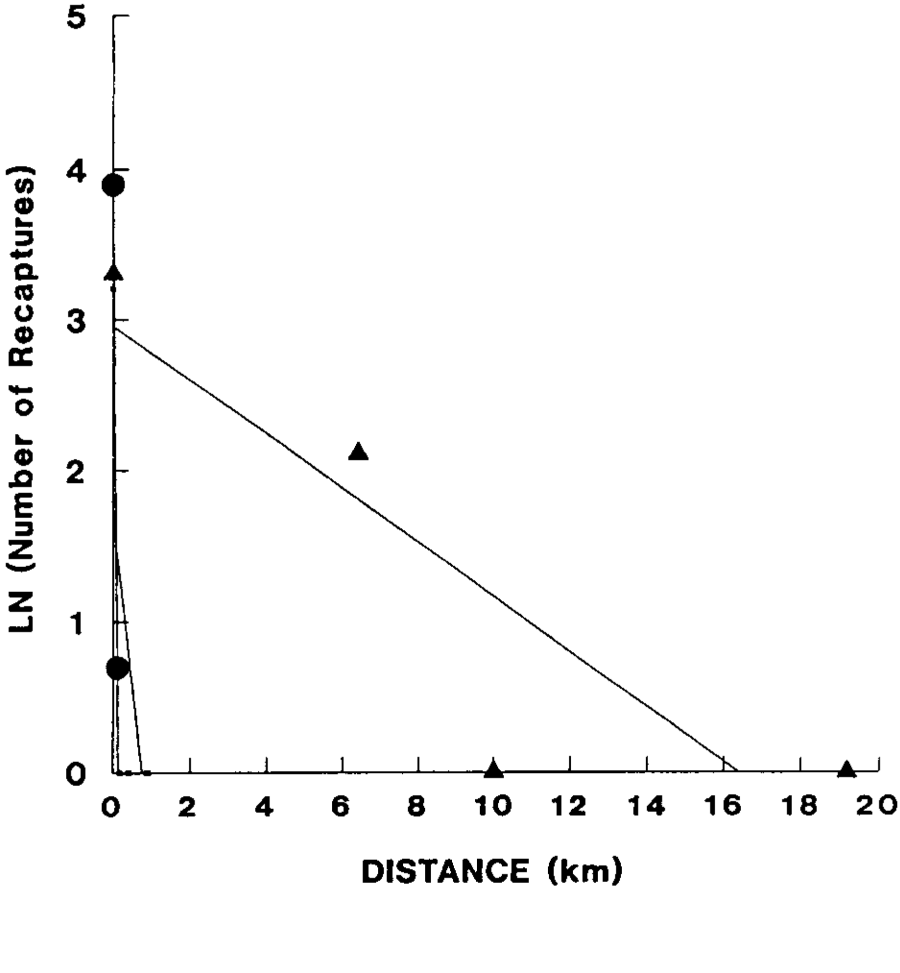

Figure 3. Number of recaptures versus distance traveled for white grunt (*Haemulon plumieri*). Small squares are for Randall (1961, 1963), large circles are from Springer and McErlean (1962) and large triangles are from Moe (1966).

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