Background Concepts for a Rotating Harvesting Strategy with Particular Reference to the Mediterranean Red Coral, *Corallium rubrum*

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Introduction

Developing a quantitative model for an exploited population which reflects its main demographic features is now a standard precondition for drawing up a management plan for the resource. It can also reveal the most important questions to be addressed by a research program in support of management.

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ABSTRACT—A simple cohort model was used as the basis for selecting the appropriate periodicity and number of separate unit areas in a rotating harvest scheme for a sedentary species, the red coral, Corallium rubrum, *in the General Fisheries Management Council for the Mediterranean area. The rotation period in years, and hence the minimum number of unit areas involved, was determined on the basis of the time to maximum biomass by a simple calculation of the yield-per-recruit type, requiring a knowledge of natural mortality and growth rates. Other criteria may be more important, however, and in general for a long-lived species, will result in shorter rotation periods. These criteria may include economic factors, criteria based on the preferred size or quality of product, or criteria that take into account the cumulative risk of illegal fishing of closed areas with time, hence the growing cost of enforcement as harvestable product accumulates. For red coral, although maximum biomass is predicted to be reached after some 15-44 years, the above considerations suggest that a rotation period of some 9-15 years would be close to optimal, taking into account a range of the above considerations. This article discusses the relative merits of rotating harvest schemes in contrast to quota management for sedentary and semi-sedentary resources or geographically isolated substocks of a mobile resource, and concludes that this approach may have considerable potential as an alternative approach to resource management.*

Red coral, *Corallium rubrum*, is widely distributed throughout the Mediterranean Sea, and, at least in the past, it has occurred in commercially exploitable concentrations off Spain, Algeria, and Sardinia, as well as being widely distributed at lower densities from the Aegean Sea and the southern and eastern Mediterranean to the Sea of Alboran inside the Straits of Gibraltar. Preoccupation has been expressed by fishermen and industry with the declining returns to an ever more sophisticated harvest sector, which has progressively exchanged primitive dragging equipment (the Saint Andrews Cross) for mixed gas diving equipment capable of operating at over 100 m depth. These concerns led to two expert Consultations (GFCM, 1984; GFCM, 1989a) where the options for future management were discussed by the industry and scientists. At the second of these, the main elements of the rotating harvest scheme presented here (Caddy, 1989) were seen as a useful basis for further discussion, and were further refined in a meeting held in Algeria on 9-11 January 1989 (GFCM, 1989b: App. E).

This paper provides a summary of the underlying considerations, not only because of their interest in the case of management of red coral resources, but for possible wider application to other sedentary or territorial resources.

Developing a population model for precious coral resources, as for any approach to fishery modelling, has to take into account the fact that population parameters are not precisely known; nor is the size of the population, the rates of recruitment and growth, or the death rates due to natural causes and fishing. It is necessary to base our models, and the resulting management regimes, on the best information available.

Alternative Approaches to Modelling Coral Populations

The first General Fisheries Council for the Mediterranean (GFCM) Technical Consultation on red coral resources of the western Mediterranean (GFCM, 1984) discussed the question of modelling red coral resources and examined the application of three types of models proposed by Garcia (1984) in the same report. These were: 1) Models that assume a mining strategy, 2) generalized production models, and 3) structural or yield-per-recruit models. The first appears relevant to short time and distance scales and describes well the strategy of fishing, especially with divers, over an individual patch of red coral.

The second modelling approach poses significant problems in terms of the definition of fishing effort, given a local availability which changes with depth, currents, bottom configuration, and distance from port (although locality-specific production models have been postulated, e.g. Caddy and Garcia, 1983). Together with the third type, simple production models depend on a dynamic pool assumption for the mixing of age groups between successive harvests. This last assumption does not accommodate well to a harvesting model that reflects the geographical dispersal of a sedentary resource on a Mediterranean-wide basis, where the mean age of the local population often reflects the time since last harvest.

In recognition of this, the first Consultation recommended that "the principle of rotations, zones opened to fishing and then closed for set periods, must be carefully studied." It was further noted that several countries and regions already had closures of coral fisheries in their fisheries legislation; notably, a 5-year closure established for coral fisheries in Sardinia and a 25-year closure provided for in Spanish legislation. A 9-year rotating closure period was apparently also practiced by Arab fishermen in the 10th Century (Grigg, 1988).

Four aspects of modelling a red coral population emerge from the biology of this organism in which it differs significantly from, for example, the more commonly modelled finfish populations, namely:

1) Populations are sedentary, and their density varies from place to place.

2) Because they are sedentary, the effects of past local harvesting remain local, at least until the population regenerates itself. In other words, the dynamic pool assumption must be rejected (Caddy, 1975).

3) Like other high-value sedentary or semisedentary organisms, harvesting (especially by scuba) tends to be in a 'pulse' fishing mode, in which local patches are cleaned out selectively, leaving only inaccessible or noncommercial individuals, before another patch is located and harvested in turn.

4) Growth of corals, and hence regeneration of exploited populations, is very slow, and as such, harvested areas are effectively removed from production for a significant period. Periods of up to 50 years have been mentioned as recovery times in Pacific fisheries (Grigg 1984).

5) However, closure of a coral fishery for such a length of time imposes unacceptable surveillance costs and leads to an increasing incentive for illegal fishing (Garcia, 1984).

Appropriate Population Models for a Precious Coral Resource

Yield per Recruit Models

The yield model used in a particular fishery should ideally reflect the likely management regime in order to facilitate its application in practice. In this sense, the dynamic pool yield-per-recruit models are not particularly well adapted to a sedentary species, unless the spatial nature of the resource is taken into account (e.g. Caddy, 1975; Gales and Caddy, 1975; Sluczanowsky, 1983). They may be useful, however, for a first treatment of an open-access resource in which we wish to know the effects of a minimum size limit and a particular level of fishing effort on the resource. Such models have been applied to precious corals by Garcia (1984) and Grigg (1984). The beginnings of a bionomic framework for population modelling based on a method of age reading of colonies have been provided for the Mediterranean red coral resources by Garcia-Rodriguez and Masso (1986a,b).

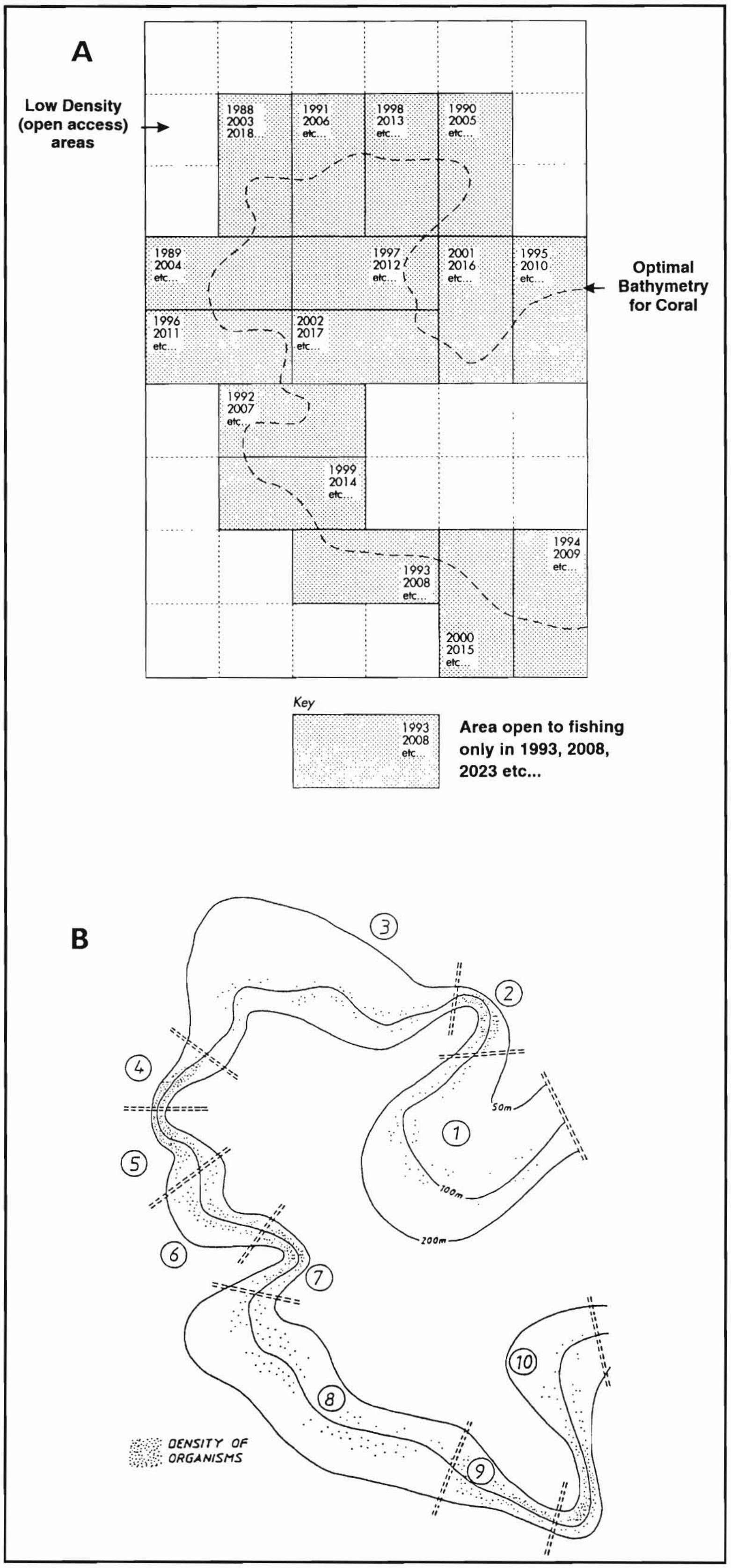
It was clear at the first GFCM workshop, however, that continuous harvesting in a sustainable way (i.e., without depleting the resource) would necessitate very low levels of annual harvest with respect to the stock size, if populations were not to be depleted. A range of estimates has been made, starting with 1.3% for Masso et al. (1986a), Grigg (1984), who mentions values of 3.5% of the stock size harvested annually as corresponding to MSY, and figures of the order of 5% in Garcia (1984). In terms of rotational harvesting, these are equivalent to dividing the stock range into roughly 73, 28-29, or 20 unit areas, respectively, and harvesting one of them completely each year. This is precisely the conceptual framework that is adopted in this paper, although it is developed from a rather different set of assumptions.

Rotating Harvest Models

The most obvious alternative management scheme to an open-access fishery for sedentary species is one where the stock is divided into subareas, whose harvesting is staggered over a period of years, thus allowing depleted stocks to recover before reharvesting. The main purpose of this paper is to explore the simplest type of model that might be developed to underlie such a management regime and how, in particular, the number of unit areas would be defined, and hence the proportion of the total biomass harvested annually. With this scheme it is assumed that the commercially valuable animals in a given unit area are all harvested (with the exception, of course, of those individuals that are not accessible in crevices, deep water, etc., which would still contribute to recruitment, and those small individuals which it is uneconomic to harvest).

Rotating harvest regimes for sedentary organisms can be represented using yield-per-recruit (*Y/R*) models with spatial components (Caddy, 1975), but these require considerable information on population parameters, which are not yet available for red coral resources. It appears, however, that the framework for this type of model can be considerably simplified for sedentary species to allow different treatments to be elaborated for geographically different subsections of the stock. The objective of this modelling and management framework is to allow harvesting strategies to be expressed in terms of the time intervals since the resource was last harvested. Implicit in this approach is the concept that evolution of the cohort biomass may be followed throughout its life history to the point at which optimal conditions for harvest are realized (Alverson and Carney, 1975).

If we take the whole population spread over an area A and divide it into n subareas which contain roughly the same fraction of the stock size or potential yield, then each of these has to support the entire fleet over a single annual season without complete closure of the whole fishery in any one year. Suppose, then, that a recovery period of y years is needed after harvest to return the stock to the optimal conditions for reharvest; then the minimum number of unit areas will be $n = y+1$ areas including the harvest year, when it is assumed, pessimistically, that



no significant recruitment survives locally (i.e., that settlement season precedes harvest). Figure 1A shows one hypothetical rotating closure scheme where, for simplicity, 15 unit areas have been defined of equal size. As noted above, it might be more appropriate to maintain the fraction of the stock size in each area constant, rather than the extent of the areas themselves, as in the alternative approach illustrated in Figure 1B.

Of course, some fraction (*B*') of the total biomass (*B*) could be excluded from the rotation scheme, or two or more unit areas could be opened simultaneously to harvesting. The first eventuality could include areas of fringe population excluded from the rotation scheme and left open to harvesting full time. Alternatively, some areas where reproduction occurs more regularly (Caddy, 1988) could be closed indefinitely as "mother lodes" or stock conservation areas. All of these options would reduce the fraction of stock size in any particular unit area, since, given a biomass of *B* tons in the whole area set aside for rotational closure, only (*B* - *B*')/n tons would be available for harvest annually from any unit area open that year.

Take a concrete example, where we suppose that $y = 25$ years, and the hypothetical biomass available to harvesting is $B = 500$ metric tons (t). The minimum number of unit areas is then 26, and the population harvestable annually should then average around 19 t. It can be seen that this approach is, in practice, equivalent to setting an annual quota, without the disadvantage of having to define the level of catch in advance. Some other advantages and disadvantages of this approach, when compared to the principal alternative management approach, namely a quota scheme, are described later in the pa-

Figure 1—A: Hypothetical rotating harvest scheme with 15-year period, beginning in 1988, and a cycle that repeats in 2003, 2018, etc. Only areas of known productivity are included; other areas are assumed to remain "open access" or to be permanently closed (reserves). B: Rotating harvest scheme in which the boundaries of each area are designed to produce roughly the same potential yield.

per. In the next section, an attempt will be made to formulate a simple model and define the number of unit areas needed in such a scheme.

Population Parameters

Although population parameter values are not precisely known for Mediterranean coral stocks, they are likely to show wide variation from place to place, and a population simulation is still useful in revealing the implications of a range of values that seems likely to encompass the actual parameter values that apply for the stock.

With respect to natural mortality rates, Grigg (1984) suggests a range of values for $M = 0.04 - 0.07$, which is equivalent to mean ages in a virgin stock of 25+ to 14+ years assuming an age at first harvest of 3+ years.

Growth in length is usually given in terms of millimeter increments per year, but presumably growth slows down for older colonies, so some growth function (i.e., von Bertalanffy) will be needed that shows this characteristic, especially for expressing growth in weight. In developing an idea of the range of values for the von Bertalanffy parameters that would be appropriate for such a long-lived, slow growing organism, it is assumed that by, say, 50 years of age, 90% of the potential growth in length has been accomplished. If we set $t(0) = 0$, it is possible to then estimate an equivalent value of K without knowing the maximum length, L_∞ from:

$$0.9 * L_\infty = L_\infty * (1 - \exp - (50 * K)).$$

This allows elimination of L_∞ from the equation, and a solution for K of approximately $K = 0.05$.

If growth in weight is assumed isometric and the value adopted for asymptotic weight of 1 kg by Garcia (1984) is used, then the growth in weight with age is given by:

$$W(t) = 1{,}000 * (1 - \exp - (Kt)) ** 3,$$

and values for weight at age for $K = 0.05$ can be generated.

Another approach was adopted by the 1989 ad hoc working group on rotating harvest (GFCM, 1989b) by fitting the von Bertalanffy equation for isometric growth in weight to weight-at-age data tabulated by Garcia-Rodriguez and Masso (1986a, b). A best-fit with constraint $W_\infty = 1{,}000\ g$ gave a value of $K = 0.035$. Although weights progressively exceed von Bertalanffy expectation after age 35, this was not felt to be relevant for shorter rotation periods.

Cohort Biomass

Given that the number of individuals from an unfished cohort (assumed initially at 10,000 individuals on recruitment) drops off with time according to

$$N(t) = N(t-1) * \exp(-M),$$

the cohort biomass (largely consisting of skeletal material) is then

$$B(t) = N(t) * W(t).$$

It is now possible to calculate biomass at age for a range of values of K and M, and to observe when the biomass is maximal, which occurs when the increase due to growth is compensated for by the loss due to natural deaths. This is then the age at which harvesting the cohort would give the maximum yield. In the case of natural stocks, this is of course impossible to achieve since there is a mixture of age classes which are mostly harvested together. The rotating harvest regime potentially comes closer to this "ideal" strategy than other methodologies, since after at least one rotation of all areas has been completed, the older age groups (with ages less than or equal to the closure duration) have presumably been protected from harvest and should dominate the catch by weight, unlike the situation with open access where, under heavy fishing, the fishery comes to depend heavily on young animals.

Values for the age at maximum biomass $t_{\max}$ are given in Table 2 for a range of values of M and K, together with the predicted time interval for maximum annual biomass increment, and the number of whole years before a range of percentage increases in biomass are predicted to be attained.

As expected, the time elapsed before maximum biomass is attained increases as K and M decline, as does the time elapsed before the other criteria mentioned above are realized. Trajectories for growth, mortality, and biomass are given in Figure 2 for two sets of trial values. Figure 3 compares the same biomass trajectory with both the annual increment in biomass with age and the percentage annual biomass increase.

Discussion

Modelling Theory

Harvests of "wild" marine resources, because they take a mixture of age classes, are usually managed (if managed at all) by means of an overall limit on the catch and/or fishing effort and by the imposition of a minimum size limit, and they are considered to be subject to continuous fishing pressure by the harvesting fleet. Occasionally, closed seasons/areas are used to supplement these measures, but for marine fish stocks, because a degree of dispersal between areas occurs, the option to subdivide the stock into different subareas does not usually exist, except where specific nursery or spawning areas may be protected (e.g. by seasonal closures).

Therefore, in finfish yield calculations, the whole stock is considered to form a dynamic pool; all members of an age group above a given age of first capture being considered as having an equal probability of harvesting at a given time. In the case of sedentary populations, harvesting subunits of the population separately is possible, using concessions, leases, or areas of open access, so that the dynamic pool assumption is only reasonable at the unit area level. Schemes of harvest, such as the rotational harvest scheme described here, then become advantageous to consider, and, as it proves, relatively easy to visualize in the form of a simple model. Although simulation is no substitute for experience in field application, this type of measure appears to be comparable to optimally managed open-access regimes with respect to the potential yield realizable, and may have advantages with respect to survival of under-sized discards and in economic terms.

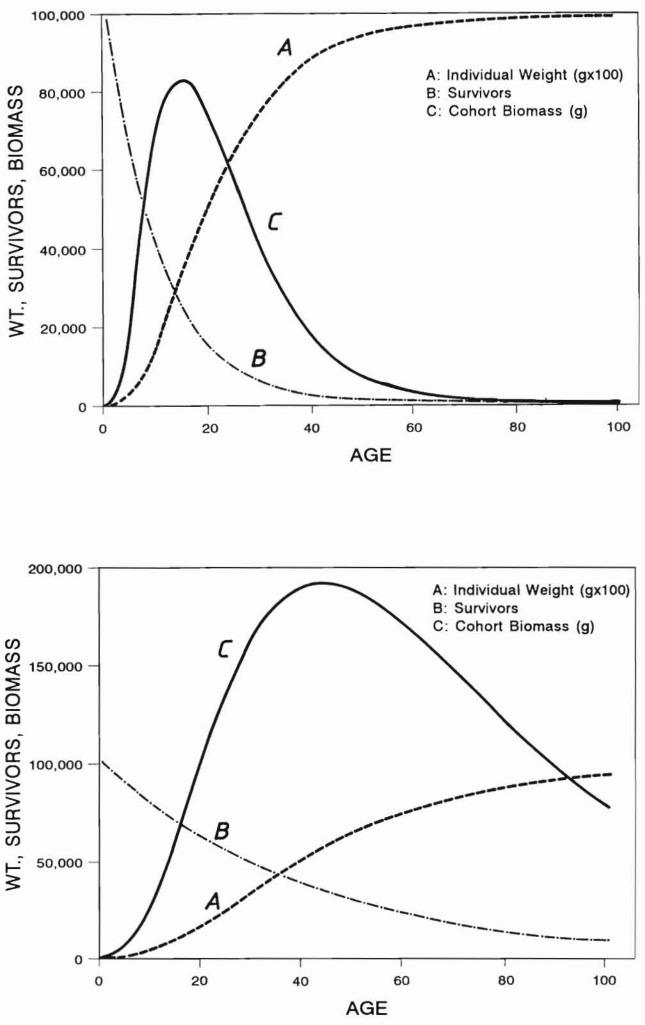


Figure 2—Trajectories of growth in weight (A), decline in numbers (B), and cohort biomass (C) with age, for (lower) M = 0.01, W_∞ = 1,000 g, K = 0.08; and for (upper) M = 0.025, W_∞ = 1,000 g, K = 0.04.

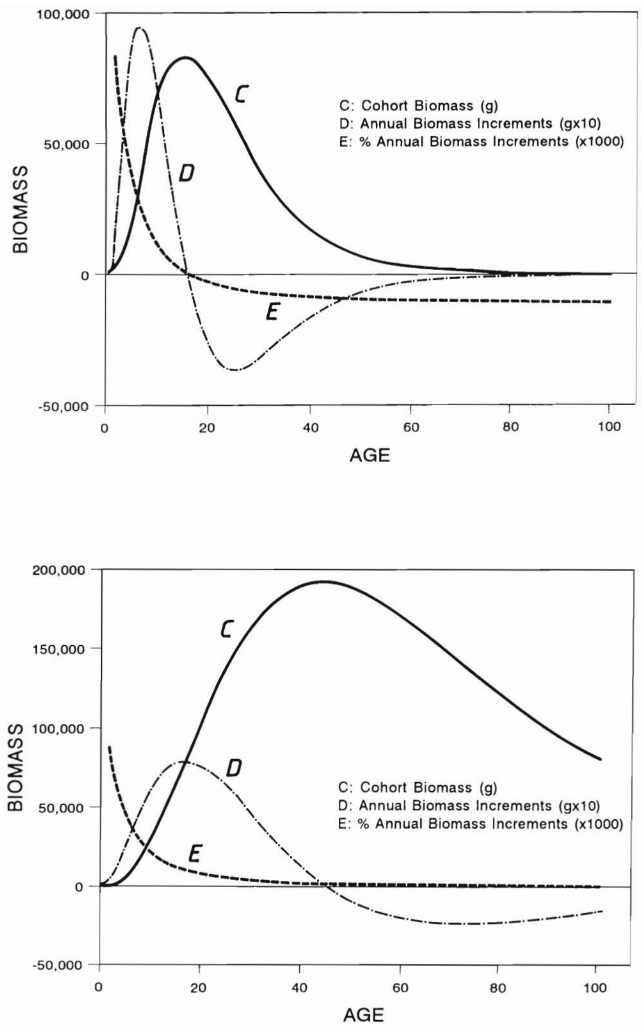


Figure 3.—Trajectories of the cohort biomass C shown for the two runs in Figure 2, compared with the annual biomass increment for the population D, and the percent annual increase in biomass E.

Future developments of the single cohort model could of course be envisaged which incorporate more than one age group simultaneously, and this may change somewhat the calculated age to optimal harvest predicted by this simple model. It seems, however, that for a variety of sedentary species, this effect may not be considerable, at least for long-lived sedentary species. Two factors (GFCM, 1989b) may be counterbalancing in the case of red coral and are not taken into account in this simple approach:

1) The work of Garcia-Rodriguez and Masso (1986a, b) confirms that red coral, like many other sessile benthic organisms (e.g. Hancock, 1973, 1979), show intraspecific competition which limits recruitment of new year classes of a sedentary invertebrate once one or several year classes dominate the substrate. These Spanish results suggest that after 3 years, recruitment to previously harvested surfaces is progressively saturated.

2) With careful harvesting, the age 2-3 colonies may largely survive to the next harvest cycle.

It will require practical experience in each case to determine which of items 1) and 2) are most important in each case, so that, for the present, there are not adequate data on density dependent recruitment to merit expanding the single cohort model. Clearly, more complex models may be developed that take into account density-dependent, or area-specific recruitment, growth, and mortality, as well as possible effects of "thinning" at some intermediate stage prior to completion of the rotation cycle. All of these aspects will require much more data to be implemented, in a situation where determining the exact optimum rotation period is less important than immediately implementing a management scheme based on a reasonable compromise for the periodicity, in which all important factors are given some weight.

The Need for Effort Control

One feature that red coral fisheries must share with fisheries for other valuable sedentary or semisedentary resources such as the abalone *Haliotis* sp., or lobsters, is that given the high unit value of the resource and the open-access nature of most fisheries, an excess of effort is inevitable in the absence of strict controls of fleet size and fishing effort. Some control of the number of entrants to the fishery is supposed, and is essential to the success of management by rotating closure. There are considerable difficulties in achieving limited license schemes, but these have the advantage that those fishermen licensed in the fishery have an incentive to protect the resource from infringements to fisheries regulations. Here we may perhaps consider also some of the practical problems facing such a management scheme by rotating harvest by comparing it with the usual quota management approach.

Rotating Harvest Schemes vs. quotas?

As we have seen, both of these management approaches aim to remove a sustainable yield from the population each year. From a yield/recruit perspective, rotating harvest schemes have the potential to provide a similar physical yield to open-access fisheries and a still higher economic yield, given that the rotation period could be adjusted to provide high proportions of those size groups commanding the highest unit price. If individuals of a given age are more valuable per-unit-weight, this should increase still more the total catch value. The spawning potential of the stock should also be greater with this management format, especially if one or more local "mother lodes" are maintained in unfished sanctuaries. Rotating harvest systems should allow significant numbers of spawners to accumulate, always assuming of course that the rotation period exceeds the age at maturity, and that some individuals, at least in adjacent areas, remain to contribute to the spawning stock in their own and adjacent areas.

From the perspective of fisheries control and surveillance, the advantages are not all one way, and both methods of management set exacting criteria for the management authority. For simple quota schemes, the need to control landings in port will have to be supplemented by some sea patrols to ensure that unauthorized fishing units are not operating once the grounds are closed or are not transshipping the catch at sea.

There will also be the need for control of fishing operations at sea with a rotating harvest scheme, to ensure that fishing is not occurring in unauthorized areas; also, a more precise control of the location of fishing will be needed. This is now feasible from a technical perspective, given that accurate position-fixing aids are now common on fishing vessels. There appear at first sight to be major problems for fisheries surveillance, which will increase progressively as the biomass on the grounds builds up. However, any vessel operating over a closed area with fishing/diving gear in operational mode, could be liable to penalties. Since, as for quota schemes, the authorized catch will be only a small proportion of the total biomass or standing stock, it is likely that with a rotational closure, the fishery will only need to operate for a small part of the year. Unlike quota schemes, however, there will not be the need for real-time gathering of catch information to ensure that the quota is not exceeded before the fishery is closed, although surveillance to detect landings of sublegal sizes, given some minimum size limit, may be desirable.

Criteria for Setting Time Periods for Rotating Closures

Given the general lack of commentary on this point in the classical population dynamics literature, one might deduce that the appropriate management criterion for harvesting a long-lived resource is the same as for a short-lived resource, namely, the realization of some optimal yield, whether expressed in economic or physical terms. It is clear, however, and has been expressed in various places, that controlling a fishery to achieve maximal yield where only a small proportion of the yield can be removed annually, imposes major problems and costs. This is especially true if the stock is long-lived and slow growing, and does not accumulate an annual increase in value which is at least equal to that considered a desirable rate of return to industry; notably, at least 10%. Hilborn and Walters (1992) noted that for unproductive stocks, such as the large whales, population growth rates of much less than 10%, from strictly economic considerations, leave little incentive to avoid the "mining" strategy described earlier, in which a large part of the stock is removed before scarcity reduces the incentive to harvest. This type of consideration must be taken into account in deciding on some alternative management strategy to "mining," which, although possibly suboptimal from the point of view of the yield it provides, would still be preferable to an open-access harvest, especially where surplus fishing effort exists beyond that needed to take the small amount of annual yield which is sustainable.

A similar perspective is outlined in Garcia (1984) with respect to coral harvests. The incentive for illegal fishing in a closed area, and hence the need for expenditure on surveillance, will go up steadily as the red coral colonies in a closed area increase in size and value. Garcia (1984) pointed out several considerations (Fig. 4) from the perspective of enforcement of rotational closures:

1) An open season will consist of two periods: An initial "useful" period when the value of daily catches exceeds the cost of fishing and a second economically wasteful period when they do not.

2) Given that fishing will be recognized to be economically unproductive immediately following closure, if penalties for infringement are significant, there will be less incentive for illegal fishing in just-closed areas; hence, surveillance can be less intense in these areas immediately following closure.

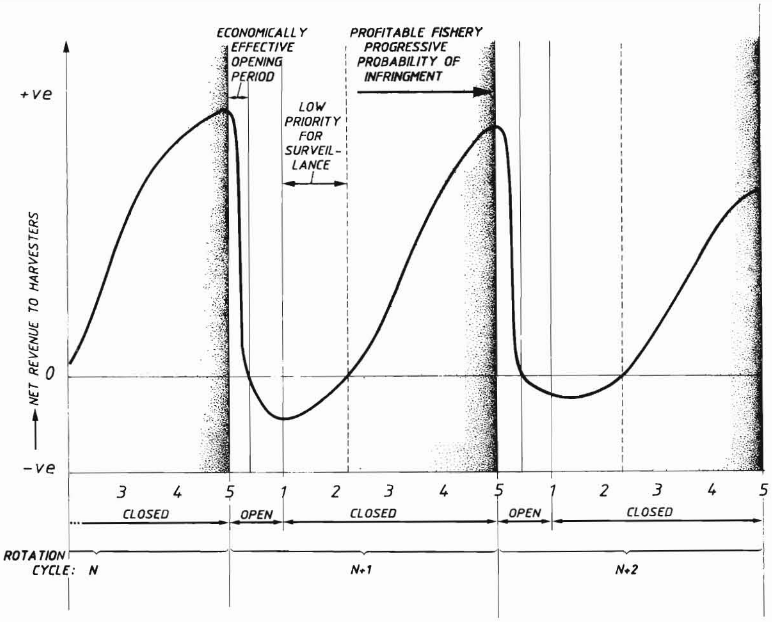


Figure 4.—Some of the features of a rotating harvest scheme (here, with a rotation period of 5 years), are shown from the perspective of control and surveillance of fishermen's adherence to the rotating closure (redrawn from Garcia, 1984).

3) The incentive for illegal fishing, and hence the need for surveillance, will increase the longer the fishery is closed, and particularly as the time of opening of a new area approaches.

Changes in Unit Value of Coral with Age

Unit value of coral depends on a range of considerations, including quality, size, and color or origin, of which colony size is of particular interest in terms of a rotating harvest scheme (Table 2). The unit value of colonies is higher for older colonies, but this is conditioned by the fact that a significant proportion of very old colonies are more likely to be of poor quality due to boring sponge, and here wastage may be higher. Small colonies with limb diameters of 6-8 mm command the lowest price per unit weight. Colonies of intermediate size are easier to process, and they provide a greater rate of return on the number of colonies harvested than very large colonies. These unit prices (Table 1), however, reflect the current size range available in the market, and it can only be speculated how relative prices might change if colonies of intermediate size dominated the market. Despite this, these data tend to reinforce the conclusion of this simple simulation that a rotation period of intermediate duration would be more favorable in terms of the type of coral available to the industry than one providing predominantly small or large colonies.

The several considerations above seem to provide a strong incentive to modify the initial "optimal" criterion considered in this paper, namely for a rotating closure designed to achieve maximum cohort biomass, which requires closures from 15 to 44 years, and replace these unrealistic "ideal" periods with shorter "suboptimal" periods calculated as in Table 1. Given these considerations, two other criteria may be suggested which give shorter rotation periods and lower yield, but would probably be more efficient and easier to enforce:

1) The time to maximum biomass increment: This is achieved after somewhat less than half of the time needed to achieve the maximum biomass.

2) With somewhat more validity from an economic perspective, one might consider setting a closure duration such that the advantages of closing the area for 1 year more would cause the percent annual increment in biomass/net revenue from leaving the resource on the ground to fall below some preset discount rate that would be at least equalled if the stock in the unit area were harvested in the current

Table 1—Results of simulations with the simple single-cohort model.

K	M	t	Biomass per 1,000 recruits (g)	Years to max. biomass increment	No. of Years to percent increment of: 50%	40%	30%	20%	10%
	0.025	44	19,871	17	5	6	8	10	16
0.04	0.05	39	80,089	13	4	5	7	9	15
	0.10	20	24,975	9	4	5	8	8	12
	0.025	35	288,551	13	4	5	7	9	14
0.06	0.05	25	141,218	10	4	5	7	9	13
	0.10	17	52,779	7	4	5	6	8	11
	0.025	30	364,110	11	4	5	7	9	13
0.08	0.05	22	198,815	9	4	5	6	8	12
	0.10	15	84,151	7	4	5	6	7	10

year. These percentages may then represent the added benefits to the industry of leaving the coral on the ground, as opposed to harvesting it and realizing an immediate economic gain. Table 1 seems to provide the basis for such a decision-making process.

The Size of Unit Areas

The size of the unit areas and their sequence of opening has obvious implications for the status of the resource and for fishery management, especially at the international level. Three considerations may be mentioned:

1) If unit areas are too large, recruitment from adjacent areas to a newly depleted zone may possibly be reduced, and stock regeneration will be more dependent on those individuals within the area which escaped harvest. (Sexual maturity is reported at ages 1-2 years for red coral so that, in theory at least, undersized individuals could contribute to population replenishment.)

2) The adverse local economic impact of protracted closure would be increased if closures are rotated always between closely adjacent areas, instead of as far as possible between different jurisdictions which are widely separated geographically.

3) In situations where multiple factors need to be resolved in deciding on the optimal rotation period, we may conclude that it may be more important to decide on and implement a rotation scheme that meets with the approval of all concerned, than to search for the "optima optimorum" for the period of rotation.

Table 2—Indicative information on prices paid in 1989 for coral comparable quality for different size ranges. Source: B. Liverino, expert in red coral industry, Torre del Greco, Italy; personal commun. in GFCM (1989b.)

	Price in Italian lire per kilogram (% purchased) by locality	
Category	Sardinia, Corsica, Yugoslavia, Palma de Mallorca, French coast (except Marseilles)	Marseilles, Costa Brava
Small, basal diam. 5 mm	100,000 (35%)	100,000 (55%)
Medium, basal diam. 8 mm	350,000 (40%)	280,000 (35%)
Large, basal diam. 11 mm	800,000 (20%)	770,000 (10%)
Extra large diam. >11 mm	1,300,000 (5%)	

Other Management Measures

Several ancillary measures that may improve the effectiveness of rotating harvest schemes were mentioned in GFCM (1989b), and they may be summarized as follows:

1) Measures should be taken to reduce harvest and incidental damage to small, unharvestable colonies.

2) Accredited coral fishermen should purchase a license for coral fishing, validated for the open area in question.

3) Individual landings should be in sealed bags, identified as to time and place fished, and registered on a duplicated tag or purchase record, with copies for the fisherman and buyer.

4) Penalties should be imposed for nonlicensed fishermen and those in possession (buyers or fishermen) of unworked coral without appropriate documentation.

5) Given that catch rates will fall rapidly after onset of the open season, a Leslie-Delury approach may be used during the open season in a monitored fishery that ensures that when mean catch rates fall below levels that are below the economic breakeven point (say, a daily average of <1.5-2 kg/day over a 2-week period (GFCM, 1989)), the season is closed early.

One potential advantage for enforcement offered by the Mediterranean red coral fishery is the existence of a well coordinated processing sector. This can largely determine the level of success of a management scheme with a controlled market. By purchasing material only at a centralized market, from licensed fishermen working in authorized areas, the buyers can help ensure that the incentive for harvesting outside these legally open areas is greatly reduced.

The Scope for Application of Rotating Closures

We may consider other situations or species in which rotating harvest schemes may find an application. The first of these is, of course, a nonmigratory behavior or reduced mixing between adjacent unit areas, where the annual diffusion rate E of the species from a unit area over the period of rotation n is such that $nE << F$, the instantaneous mortality rate exerted on the local population during the harvest in the nth year of the rotation. Situations where this may apply, apart from the obvious case of sedentary or semisedentary species (e.g. many shellfish), also include cases where a mobile species is effectively divided into subunits as adults, e.g. fish stocks of islands in an archipelago or in a series of lagoons or lakes, or even the fish populations of individual coral reefs where a degree of population isolation exists as adults. Two other advantages of this management methodology may be that 1) genetic selection against fast-growing strains, which is an inevitable long-term consequence of continuous harvesting with size-selective gear, is likely to be attenuated, and 2) the transition away from open-access regimes to some form of area-leasing arrangement, is facilitated.

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