MANAGEMENT AND ASSESSMENT OPTIONS FOR THE CRAB FISHERY AROUND SOUTH GEORGIA

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Abstract

A new fishery for the lithodid crab, *Paralomis spinosissima*, started in Subarea 48.3 in 1992. The fishery is also new to CCAMLR, both in terms of the species and fishing gear. We provide an overview of the management options for crab fisheries in general and then consider these options in the context of this crab fishery with specific reference to the principles of the CCAMLR Convention. We outline the assessment methodologies and data requirements for the implementation of the various management options.

All the features of the fishery and the objectives of the Convention point to the need for a conservative approach to management. Such an approach includes the use of catch/effort controls in addition to the 'size-sex-season' controls. Implementation of both sets of controls relies on information on the growth and life-history of *P. spinosissima*. Implementation of the catch/effort controls also requires estimates of stock abundance, which could be obtained by depletion methods. Consideration should also be given to the creation of refuges, though careful attention must be given to their design. One of the main aims in designing a management plan is to allow the fishery to develop at a rate compatible with the expansion of the information base available for assessment.

Résumé

En 1992, une nouvelle pêcherie de crabes lithodidés, *Paralomis spinosissima*, a été mise en place dans la sous-zone 48.3. Pour la CCAMLR, cette pêche est toute nouvelle tant en ce qui concerne l'espèce que les engins de pêche. Nous exposons brièvement les diverses méthodes de gestion des pêcheries de crabes en général puis les considérons dans le contexte de cette pêcherie en tenant compte spécifiquement des principes de la Convention de la CCAMLR. Nous exposons les méthodologies d'évaluation et les données nécessaires pour l'application des diverses méthodes de gestion.

Compte tenu des caractéristiques de la pêcherie et des objectifs de la Convention, il conviendrait d'adopter une gestion dont l'approche serait propice à la conservation. Cette approche comporterait des contrôles de capture/effort de pêche ainsi que des contrôles de "taille-sexe-saison". L'application des deux types de contrôles nécessite des informations sur la croissance et le cycle biologique de *P. spinosissima*. De plus, l'application des contrôles de capture/effort nécessite des estimations de l'abondance du stock, estimations que pourraient fournir les méthodes de chute. Il conviendrait également d'examiner la création de refuges, en attachant une attention particulière à leur conception. L'un des objectifs principaux de l'établissement d'un plan de gestion est de permettre à la pêcherie de se développer à un taux compatible avec l'expansion de la base d'informations dont on dispose pour effectuer les évaluations.

Резюме

Новый промысел крабов литодид, *Paralomis spinosissima*, был начат в Подрайоне 48.3 в 1992 г. Этот промысел является новым для АНТКОМа в плане как эксплуатируемого вида, так и используемого промыслового оборудования. В настоящей работе дается обзор вариантов управления промыслом краба в общем, а затем эти варианты рассматриваются в контексте данного промысла краба с конкретной ссылкой на принципы Конвенции АНТКОМ. Описываются методологии оценок и требования к данным для внедрения различных вариантов управления.

Все аспекты данного промысла и цели Конвенции указывают на необходимость принять консервативный подход к управлению. Такой подход включает в себя контроль за выловом/усилием в дополнение к контролю типа "размер-половая принадлежность-сезон". Внедрение обоих видов контроля зависит от наличия информации по росту и жизненному циклу *P. spinosissima.* Внедрение контроля за выловом/усилием потребует оценок численности запаса, которые могут быть получены при помощи методов истощения. Также следует рассмотреть вопрос об установлении охраняемых участков, хотя их разработке следует уделить особое внимание. Одна из главных задач при разработке плана управления - позволить промыслу развиваться в темпе, совместимом с расширением имеющейся для оценки информационной базы.

Resumen

En 1992 se inició en la Subárea 48.3 una nueva pesquería de la centolla litódida, *Paralomis spinosissima*. La pesquería es nueva también para la CCRVMA en cuanto a la especie y a los artes de pesca. Proporcionamos una reseña de las opciones de gestión para las pesquerías de centollas en general y luego examinamos estas opciones en el contexto de esta pesquería en particular con específica referencia a los principios de la Convención de la CCRVMA. Detallamos los métodos de evaluación y los datos necesarios para la puesta en marcha de diversas opciones de gestión.

Las características de la pesquería y los objetivos de la Convención están orientados hacia un enfoque moderado de gestión. Tal enfoque comprende la utilización de controles de captura/esfuerzo además de los controles en cuanto a "talla-sexo-temporada". La implementación de ambos controles depende de la información sobre el crecimiento y el ciclo biológico de *P. spinosissima*. La implementación de los controles captura/esfuerzo también depende de los cálculos de abundancia del stock, que se podrían obtener de los métodos de merma. Se deberá considerar además la creación de santuarios, prestándose una minuciosa atención a su diseño. Uno de los objetivos principales es el diseño de un plan de gestión que permita el desarrollo de la pesquería a un ritmo que sea compatible con la información básica disponible para su evaluación.

Keywords: management, crab fishery, *Paralomis spinosissima*, assessment methods, refuges, CCAMLR

INTRODUCTION

In 1992 a fishery for the lithodid crab, *Paralomis spinosissima*, was started by one fishing vessel in Subarea 48.3 (Otto and MacIntosh, 1992). *P. spinosissima* had not been targeted in the CCAMLR Convention Area before this fishing trip, so there are no time series of commercial or biological data. Apart from the data collected on the first fishing trip, there is very little general information about this particular species. The fishery is also new to CCAMLR in that it is the first crab fishery and the first trap fishery about which the CCAMLR Scientific Committee is required to provide advice to the Commission. In this paper, we aim to provide an overview of the management options for crab fisheries in general. We then consider these options in the context of the crab fishery in Subarea 48.3 with specific reference to Article II of the CCAMLR Convention. In the final section, we consider the assessment methodologies and data requirements for the implementation of the various management options.

GENERAL MANAGEMENT OPTIONS

Most lithodid crab fisheries are managed by at least a minimum of regulations known as the 'size-sex-season' approach. Such regulations are based on the following rationale (Otto, 1986):

Males only:
Maximise recruitment potential of the female stock.

Size limits:
Protect recruitment, by allowing males at least one

'season' to contribute to reproduction before becoming vulnerable to capture. Maximise yield-per-recruit. (Base catch limit on the abundance of males of legal size and above.)

Seasonal closures:
Protect recruitment, by avoiding disturbance during moulting and mating periods (in seasonal stocks, males moult in spring, ~1 month before females, facilitating mating between hard-shelled males and soft-shelled females). May also include the prohibition of the landing of soft-shelled crabs.

Such measures would in any case usually be adopted by industry to maintain product quality and maximise processing efficiency. Immature (small-clawed and short-legged) males and females give low meat yields per unit processing time. Soft, recently moulted crabs give poorer quality meat, soft and watery in texture, with far lower meat yields per unit fresh weight.

Many crustacean fisheries also have restrictions on destructive gears such as trawls or tangle nets, often limiting gear to pots only, so as to minimise the handling mortality of female and under-sized male crabs.

In addition to the above measures, the biological and economic stability of the larger, data-rich crab fisheries may be further managed by a range of catch and effort controls. Most crustacean stocks appear to have highly variable recruitment and fluctuate widely in abundance. Hence, for example, management of the Alaskan king crab is aimed at a target exploitation rate, defined as the ratio between the catch and the biomass of the exploitable part of the stock. The target for the Alaskan king crab is between 20 and 60% depending on whether present abundances of legal-sized and pre-recruit crabs are increasing, stable or decreasing (Otto, 1986). Quotas are set after predicting abundances by annual trawl surveys. Catches, catch-per-unit-effort (CPUEs), sizes and moulting of crabs are monitored in real time, and the fishery may be closed before the nominal end-of-season, either when the quota is reached or for other biological reasons. Exclusive area licenses and pot limits have also been imposed to protect local fleets and restrict total fishing effort.

Another management tool which can be used in combination with those discussed above is fishery refuges (or refugia). Refuges have been used as a management tool with a variety of species, including lobsters in Florida (e.g., Davis and Dodrill, 1989) and New Zealand (Cole *et al.*, 1990) and crabs in Japan (Yamasaki and Kuwahara, 1990). In many cases refuges are established with a view to remedying over-exploitation problems and rebuilding stocks (e.g., Tegner, 1993). However, fishery refuges can potentially enhance fishery yields by increasing abundance, mean individual size, reproductive output and recruitment. A refuge can provide a useful experimental control area against which the effects of harvesting in other areas can be measured. Biological data from refuges can, for example, be used to estimate life-history parameters for an unexploited population. For example, Johnston and Bergh (1993) estimate survivorship for the South African rock lobster, *Jasus lalandii*, using data from a lobster sanctuary established in 1963. Whether the population in a refuge is really unexploited or not will clearly depend on the migration/dispersal patterns within the stock. If the animals are highly migratory, the stock structure in the refuge could actually be quite similar to that outside.

The main difficulty of implementing this approach lies in determining the appropriate size, number and locations of refuges to ensure their efficacy. This is discussed here under the heading 'Refuges'.

MANAGEMENT OPTIONS IN THE CONTEXT OF CCAMLR AND THIS PARTICULAR CRAB FISHERY

The CCAMLR Convention

It is necessary to view the management options for the crab fishery around South Georgia together with the requirements of Article II of the CCAMLR Convention. The objectives in sub-paragraph 3 of Article II may be paraphrased as follows:

(i) to prevent a decrease in the abundance of the harvested population to below the level that would give greatest net annual increment and stable recruitment;

(ii) to maintain ecological relationships between harvested, dependent and related populations; and

(iii) to prevent changes or to minimise the risk of changes in the marine ecosystem that are not potentially reversible over two or three decades.

Practical problems regarding the interpretation of these objectives have been highlighted (e.g., Basson and Beddington, 1991) and there is clearly a need to relate these objectives to particular, measurable quantities, to allow monitoring and ensure that the objectives are met. The first task is, however, to ensure that the objectives are addressed by the management options in one way or another.

The first objective would be addressed by preventing the spawning stock from declining to unacceptably low levels, though what is unacceptably low has of course not yet been defined, and the level which gives the greatest net annual increment is unknown. All three aspects of 'size-sex-season' management are aimed at achieving this objective. Refuges could also play an important part in protecting the spawning stock and recruitment.

As far as the second objective is concerned, it is fair to say that crabs play a much less important role in the ecosystem than does, for example, krill. This implies that the ecosystem approach is not quite as crucial as in the case of krill, and a single-species approach would not be unreasonable, at least at the start. It is, however, still important that at this early stage the dependent and related species are at least identified. This matter also raises the question whether the parasite, *B. callosus*, should be considered as a dependent species or a nuisance! The establishment of refuges should contribute to the maintenance of ecological relationships.

The third objective can partly be addressed by limiting catch and/or effort to ensure that the fishery does not develop at a rate that is incompatible with (i.e., much faster than) our ability to assess the stock and obtain the necessary information about the stock dynamics. Refuges may well improve the chance of reversibility of, for example, a stock decline or ecosystem changes in areas where crabs are harvested. The third objective also suggests that taking a cautious and conservative approach to management would be appropriate and in the spirit of the Convention.

The Fishery for *P. spinosissima* in CCAMLR Statistical Area 48 (or Subarea 48.3?)

The main characteristic of this particular crab fishery is that it is a new fishery for which data from only a single fishing season are available. Furthermore, this particular species is not fished elsewhere, so biological information is also limited. It is also fair to assume that the initial phase of the fishery exploited the accumulated, previously unexploited stock.

The second important characteristic of this particular crab fishery is the relatively high prevalence of rhizocephalan parasitism which renders infected males and females sterile. This is discussed in full in Basson (1994). At this stage it is sufficient to note that even in the absence of a harvest, a non-zero prevalence of rhizocephalan parasites may imply that the spawning stock is already below the level that would be associated with no parasitism. The way in which this affects recruitment is of course dependent on the relationship between stock and recruitment, which is unknown.

These characteristics suggest that a conservative approach to management is appropriate and highlight the need for catch/effort controls in addition to the 'size-sex-season' management approach. It is important to avoid a situation where the growth of the fishery outpaces improvements in our ability to assess and manage the stock. There are many advantages in adopting effort rather than catch controls and this has been recognised by CCAMLR (e.g., SC-CAMLR, 1993a). Effort controls are subject to fewer sources of error than catch controls and are particularly appropriate when stock size fluctuates widely. In this fishery there is a high likelihood of mortality of discarded animals. The total landings would only reflect mortality as regards retained animals. The effort can be related to the total mortality provided that estimates of total catch-per-trap, including discards, are available for some sets.

There is a further question. The conservation measure with respect to the crab fishery (Conservation Measure 60/XI) currently applies to the whole of Statistical Area 48. This may not be appropriate. For example, the current size limit is based on information from South Georgia and Shag Rocks, but the conservation measure implies that if fishing for crabs is conducted anywhere else in Statistical Area 48 (e.g., around the South Orkney or South Sandwich Islands) the same size limit will apply. The catch and effort regulation also implies that the total catch may (in theory) be taken from some subarea other than 48.3.

In terms of management, this is clearly a question of 'stock structure'. The general principles of management are likely to be identical, irrespective of stock structure or area involved, but the details may well differ. Answers to such questions are never easily found, and the most sensible approach is to ask what the options are, and which ones are more conservative and robust to errors in our assumptions.

A conservative approach would be to manage each 'concentration' or local population as if it were a stock. It is, however, important to consider the possible recruitment mechanisms: for example, are the larvae free-swimming and do larvae from a local population contribute to recruitment to that population alone or to recruitment to all local populations? If local populations are relatively closed, then overfishing of one is unlikely to seriously affect the other populations. If local populations are open (at least at one stage in the life cycle) then overfishing of one could seriously affect the other local populations.

Summary

It would be sensible and in the spirit of the Convention to adopt a management strategy based on the 'size-sex-' and (possibly) 'season' approach. It would also be desirable to restrict or ban the use of destructive gear and introduce mesh regulations to limit the number of small/female crabs that are captured and hence minimise extra mortality regarding these categories. The specific details of the management approach should, however, take into account the possible effects of mesh changes on the harvesting of animals bearing rhizocephalan parasites (see 'The 'Size-Sex-Season' Approach').

In addition to the 'size-sex-season' approach, it is essential to use some form of catch/effort control. There are many justifications for such a conservative approach. First, there is a shortage of data and biological information. Second, recruitment may be highly variable and the abundance of legal-sized males may therefore also fluctuate wildly (see 'General Management Options'). Third, initial catches of the unexploited stock are likely to be far higher than sustainable long term catches. Fourth, it is crucial to avoid a situation where the fishery expands at a rate which is incompatible with our ability to assess, monitor and manage the stock. In the light of the effect of rhizocephalan parasitism on the spawning stock, it is even more crucial that the 'size-sex-season' approach is supplemented by a control on catch and/or effort.

The establishment of refuges would address all three objectives set out in Article II of the Convention (see 'The CCAMLR Convention') and could enhance the yield from the fishery. Refuges are also invaluable as experimental control areas and areas for scientific research on the dynamics and life-history parameters of an unexploited population.

ASSESSMENT METHOD AND DATA REQUIREMENTS

The implementation of any management approach is dependent on the availability of basic information about the stock that is being harvested. One of the main features of the *P. spinosissima* fishery is the shortage of data, mainly because the fishery has so far only operated in one season. Some parameters (e.g., size at sexual maturity) can be estimated from relatively limited data and revised as more data become available. Other parameters or relationships (e.g., stock abundance or stock-recruitment relationships) are far more difficult to estimate from limited data, and may even be difficult to estimate from a large body of data! The 'size-sex-season' approach is relatively easy to implement whereas the catch/effort approach requires estimates of abundance and productivity and is therefore more difficult to implement. Determining the appropriate number, size and location of refuges is probably the most data-intensive and challenging of the three approaches. The following three sub-sections deal with each approach in turn.

A general comment that applies to all three approaches is that the methods underlying the management approaches should be revised and improved as more data become available. Some of the methods outlined below are specifically aimed at the problem of a shortage of data at this early stage in the fishery and may become less appropriate as more data are collected.

The 'Size-Sex-Season' Approach

The 'sex' aspect of this management approach is very simple to implement because males and females are easily distinguished. The 'size' aspect requires an estimate of size at sexual maturity, for males. Basic morphometric data, including carapace length, width and, most important, chela height are needed to do this.

Otto and MacIntosh (1992) have used the standard method for determination of size at male maturity, and made sensible assumptions regarding growth rates and reproductive activity. However, the chelae allometry method estimates size at 'morphological maturity' which may be considerably less than size at 'functional maturity'. For certain lithodid species, including *P. spinosissima*, the estimated 'size-at-maturity' is the size at which the chelae *start* growing at a faster, adult rate (morphological maturity). It may then be some years or moults before the claws of such crabs are sufficiently developed to hold female crabs in a mating embrace or to defend them from other intending males or predators and thus contribute successfully to the next generation (functional maturity). A precautionary approach should thus acknowledge the possibility that breeding success may not be guaranteed by a size limit determined by this method. Although the size at morphological maturity could also be above the size at functional maturity, an error of this kind would be conservative. Animals that are functionally mature would (incorrectly) be assumed immature and this would imply under-estimation of the breeding population.

The application of closed seasons to protect breeding activities requires a basic knowledge of the life history of the species. Information on the timing of moulting and mating are of particular relevance. This kind of information is also of relevance to decisions about appropriate levels of exploitation because it relates to the productivity of the stock.

As a deep water species, it is possible that *P. spinosissima* may be a non-seasonal breeder, for which closures are inappropriate. From the information in Otto and MacIntosh (1992) however, it is also possible that *P. spinosissima* reproduces biennially and the stock in July 1992 was approaching its normal winter state with certain females brooding uneyed eggs and others with eyed eggs. Such an understanding can only be gained from at least one year's time series of fine scale, spatial and temporal information on the moulting and reproductive stages of both males and females.

Regulations to limit the use of destructive gear and mesh regulations for pots are mainly aimed at reducing the incidental capture of individuals that are of sub-legal size. This should reduce the incidental mortality. As noted by Otto and MacIntosh (1992), this should be enforced in the waters around South Georgia, and consideration should also be given to an extra restriction on mesh size (larger than at present) to minimise the capture of small/female crabs.

An increase in mesh size is also likely to reduce the number of infected animals that are captured, since most infected crabs are smaller than legal-sized crabs. An increase in mesh size may therefore not be desirable if the aim is to harvest or destroy infected animals (Basson, 1994).

Catch and Effort Control

Implementation of the catch/effort approach requires estimates of abundance and productivity. The question is how to obtain estimates of these quantities, particularly in this case where data are limited.

One approach is to look at similar species for which more information is available. Any prediction of catches from those observed in other stocks is obviously dependent on the stocks used for the comparison, so it is wise to look at more than one related species. Otto and MacIntosh (1992) compare *P. spinosissima* to the golden or brown king crab, *Lithodes aequispina*, and suggest that the potential yields of these two species may be similar. *P. spinosissima* (maximum size ~125 mm) is a far smaller crab than *L. aequispina*. The potential yield of *P. spinosissima* should then be lower than that of *L. aequispina* because crabs large enough to process will moult less frequently than equivalent-sized *L. aequispina*, being nearer to their asymptotic size. In addition to this size effect, *P. spinosissima* may also of course be less abundant than *L. aequispina*. If the comparison is instead made with the stone crab, *L. murrayi*, which is more similar in size, the potential of the South Georgia fishery is far less certain. Off the coast of Namibia, *L. murrayi*, is found over at least 300 n miles of the continental shelf, from 22° to 27°S and between 500 and 700 m, at the lower end of the depth range of *P. spinosissima*. In 1979, a single fishing vessel reduced the CPUE of the stock from 3.4 to 0.4 kg/pot in only six months fishing, at which point fishing ceased (Melville-Smith, 1982). Catch rates of *L. murrayi* around the Crozet Islands are also insufficient to support commercial fishing (Miquel *et al.*, 1985). In the northern hemisphere, the deep-sea king crab, *L. couesi*, is found in small numbers on the continental shelf and seamounts from 384 to 1 125 m in the Gulf of Alaska (Somerton, 1981) but, unlike *L. aequispina*, is not known to support any commercial fishery.

Sustainable annual catches may also be estimated from abundances and growth/mortality rates by such methods as those used by Beddington and Cooke, 1983. Growth/mortality parameters may be assessed by tagging methods, but only at considerable observer cost. From the available data, useful information on growth could be gained from size-specific moult frequencies. In general, moult frequency is more variable between crab species than the percentage moult increment and is thus the major determinant of growth rates. It is likely to decline to once every two to three years in the largest, most exploitable animals. The size at which moulting occurs less than once a year can often be simply estimated and gives a useful measure of the turnover of the stock. It is unlikely that moulting of adults is annual in such a deep-sea crab, and the potential yearly catches must then be only a small fraction of the initial, unexploited biomass (probably not more than 10%).

Knowledge of stock size is relevant to two aspects of management. First, when combined with information on growth and productivity, it provides some indication of appropriate levels of harvest. Second, it is essential in determining whether the objectives of the Convention are being met. There are of course various methods for stock assessment, some of which are more data-intensive than others, and some of which are more appropriate for crab populations than others (e.g., Caddy, 1986).

One of the *ad hoc* methods that was used at the 1992 meeting of the CCAMLR Working Group on Fish Stock Assessment (SC-CAMLR, 1993b) to obtain preliminary 'guideline' estimates of stock size involved the calculation of an effective pot fishing area. This is fraught with difficulty. Such areas are not simply related to the distance between pots but depend on the water currents, the substrates, the baits used and the detection abilities of the animals. In such deep water scavengers, food detection is likely to be highly developed, and there are clearly strong possibilities of overestimating abundance by such methods. Some of these potential biases were recognised by the Working Group (e.g., SC-CAMLR, 1993b - paragraph 6.16).

As an alternative, estimating abundances (and managing exploitation rates) by depletion methods should be possible for this stock. Leslie estimates of abundance have been successfully fitted for both large and small crab fisheries (e.g., Otto, 1986; Elner and Bailey, 1986; Campodónico *et al.*, 1983; Hoggarth, 1991). For this purpose, however, information must be available both on spatial distribution of fishing effort throughout the season and on the distribution of life history cycles over time. First, fishing effort data will enable local stock depletions to be discriminated from the overall reduction of the stock. Second, life history data will be necessary both to explain changes in observed abundances caused by seasonal migrations rather than fishing and to predict changes in catchability associated with seasonal moulting activity. Also, improvements in catch and fishing effort data will be needed, particularly with regard to the size distribution of daily catches and the soak-times of different strings. Data on as fine a spatial and temporal scale as possible are essential because of the size and heterogeneous nature of the terrain. Only after investigation of data at the finest scale can one determine whether aggregation of data would be appropriate.

It is also possible to estimate abundance from trawl surveys. This is a costly exercise, and in this particular case it seems unlikely that management could rely on a regular (annual) trawl survey, at least at this stage.

The bottom trawl survey by the *Falklands Protector* in January 1992 was mainly aimed at finfish, but some anomuran crabs, mainly *P. spinosissima*, were caught in the trawls. It is therefore theoretically possible to obtain standard swept area estimates of abundance. There would obviously be many caveats associated with such estimates. First, the type of gear used is not really appropriate for catching crabs, and this raises questions about catchability. Second, the area trawled only included depths up to 500 m whereas the fishery operated in the depth range 200 to 830 m (Otto and MacIntosh, 1992). Both these factors are likely to lead to underestimation of stock size. Third, the sample sizes were small, particularly at Shag Rocks. Fourth, because of the small sample sizes it is not feasible to estimate the stock size of commercially-sized male *P. spinosissima*, though most crabs caught were of this species.

Standard swept area estimates (e.g., Saville, 1977) were nonetheless obtained because of the paucity of other information on abundance. The estimate of crab stock size in three depth strata (50-150, 150-250 and 250-500 m) is 796 tonnes (CV = 19.5%, 67 stations) at South Georgia. The estimate for Shag Rocks is based on only 13 stations and amounts to 28 tonnes (CV = 65.8%). Unfortunately, information on crabs from other UK bottom trawl surveys is inadequate to obtain comparable indices of abundance for other years.

Although there are many caveats and problems associated with the above estimates, there are also many caveats associated with the estimates presented in SC-CAMLR (1993b). The swept area estimates contrast with the preliminary estimates of potential yield for Subarea 48.3 of 2 210 tonnes or estimates of commercially-sized crabs of between 48 000 and 155 000 tonnes (SC-CAMLR, 1993a). This very large uncertainty only highlights and reiterates the need for a conservative approach.

The methods noted in the proceedings of the CCAMLR Workshop on the Management of the Antarctic Crab Fishery (SC-CAMLR, 1993c) are also available for consideration. Point transect theory methods, in particular trapping webs, may be appropriate for estimating the density of crabs. The 'trapping web' design consists of lines of equal length radiating from a single point and the same number of traps are located on each line at equally spaced intervals. The traps are thus in rings of increasing distance from the centre of the web. The data are the number of captures for each ring of traps. The theory, assumptions and estimation procedures for this method are given in detail in Buckland *et al.* (1993).

Refuges

Refuge areas (or refugia) that are permanently closed to fishing can be a useful 'safety net' and a useful management tool with potential benefits to the fishery (see 'General Management Options'). It is not difficult to enforce such a regulation: satellite transponders may, for example, be used to ensure that no fishing occurs in the refuges. The main difficulty lies in defining refuge areas, not only in terms of location, but also in terms of number, size and shape. Although design considerations for marine fishery refuges have received relatively little attention, many studies highlight the importance of properly designed refuges (Carr and Reed, 1993; Dugan and Davis, 1993; Tegner, 1993).

With very little information on the life cycle or distribution of a species, random allocation of a refuge area may seem an attractive approach, but may bring a false sense of security. Random allocation may, for example, protect a part of the population which is not particularly productive (for whatever reason), or may define an area which is used as a migration route where animals only spend a very small part of their life cycle. It is unlikely that such a refuge would achieve the desired management objectives.

Basic knowledge of the population dynamics through the whole of the life cycle, as well as information on the spatial distribution and any migratory movements, are necessary for defining refuges. Information on oceanographic and habitat characteristics needs to be linked with the species information when determining the location of refuges. The importance of knowledge about larval drift or the lack of larval drift for the definition of refuge areas is highlighted by MacCall (1990) and Carr and Reed (1993).

The location selected for a refuge should include all the habitats used by the various life stages of the stock, particularly including the adult breeding and feeding grounds, ideally in adjacent sites (if this is compatible with the dispersal patterns). Some animals could then be fully protected all their lives, within the reserve areas, and this would provide recruits to the stock outside. The requirement for such an understanding of the spatial aspects of life histories reinforces the need for reporting biological data on as fine a scale as possible.

The most appropriate size for refuges depends basically on the scale of dispersion, with large refuges being appropriate for more wide-ranging stocks and smaller ones for essentially sedentary species, 'reseeding' only the areas near to them. In practical terms, one large refuge would be more easily enforced than several small ones.

Two general points regarding the implementation of refuges were raised in a paper presented at a recent Symposium on Marine Harvest Refugia (Dugan and Davis, 1993). The first point was that the effectiveness of refuges should be evaluated and tested. This implies data collection prior to refuge establishment, as well as continued scientific sampling from the refuges and, of course, continued data collection from the fishery. The other point was that the approach to management using refuges should be experimental. Experimental refuges of different shapes and sizes should be established and investigated to address issues such as their efficiency and design.

It is clear that we do not yet know enough about the system under consideration to design a refuge properly. We are, however, in the pleasant situation that there is no immediate, urgent need to establish a refuge to rebuild an over-exploited stock, as has generally been the pattern with the establishment of refuges in other fisheries. There are other management options available and currently in force, and therefore we would not be relying on a refuge alone to meet the objectives of the Convention. It would then not be inappropriate to locate a refuge more or less randomly. This may be an excellent opportunity for establishing one or more experimental refuges, but these areas must be sampled regularly, either by scientific surveys, and/or by carefully controlled commercial operations.

SUMMARY AND CONCLUSIONS

All the main features of the crab fishery for *P. spinosissima* and the objectives of the Convention point to the need for a conservative approach to management. This conservative approach includes the use of catch/effort controls in addition to the 'size-sex-season' controls. Implementation of both sets of controls relies on information on the growth and life-history of *P. spinosissima*. Implementation of the catch/effort controls also requires estimates of stock abundance. It should be possible to estimate abundance using depletion methods which require catch and effort data on appropriate spatial and temporal scales. These data, together with basic biological data (e.g., size, sex, maturity, parasitism) from the retained and discarded parts of the catch, are essential to the implementation of the management approaches identified above. The data requirements are given in more detail in Basson and Beddington (1993).

Consideration should also be given to the establishment of one or more refuges where crabs are not commercially harvested. In addition to the potential advantages for the fishery, such areas are valuable as research or experimental control areas where scientific sampling should be conducted regularly. Careful attention should be given to the design of refuges if they are to be effective management tools. An experimental approach to establishing refuges may be appropriate for this fishery, provided that the overall management plan does not solely rely on the refuges to meet the objectives of the Convention.

Apart from the difficulties due to a lack of data and information on this species, this fishery provides an ideal opportunity for innovative and effective management from its inception. One of the most important aims should be to allow the fishery to develop at a rate that is compatible with, and not faster than, the expansion of the information base available for assessment, monitoring and management. It should be feasible to design a management plan that achieves this goal.

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