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DEFINING SMALLER-SCALE MANAGEMENT UNITS TO FURTHER DEVELOP THE ECOSYSTEM APPROACH IN MANAGING LARGE-SCALE PELAGIC KRILL FISHERIES IN ANTARCTICA

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Abstract

This paper discusses the principles and approach required for developing small-scale management units to take account of predators' needs when managing the fishery for Antarctic krill. It provides a theoretical foundation for considering the scales of management units involving the integration of local populations of harvested species, foraging areas of predators, fishing grounds and the potential influences of the environment, including oceanography and metapopulation structure of the harvested species. The integration of these components involves two different types of unit: the 'harvesting unit', which is at the scale of the metapopulation of the harvested species, and the 'predator unit', which does not have to be a relatively self-contained ecosystem but should be sufficiently independent for fishing in that unit not to inadvertently affect predators being monitored in other units. The South Atlantic region (Area 48) is used to illustrate how to define predator units. The derived conceptual model is then used to formulate an approach for developing fisheries on prey species, notably krill, in other harvesting units. The manner in which predator units can be used to help the CCAMLR Ecosystem Monitoring Program (CEMP) provide strategic advice on the effects of fishing is discussed. In general, the early acquisition of information on the distribution of local populations of krill and the potential foraging densities of predators from within a harvesting unit (i.e. abundance of predators, distribution of colonies and foraging range) will provide a means of circumscribing predator units as well as undertaking an assessment of long-term annual yield. It is proposed that the early development of the fishery could be concentrated in a small number of units in such a way that the relative fishing intensities in those units are equivalent, although not necessarily equal, to the intensity expected across all units once the catch limit had been reached. Other units in which fishing was not occurring could be monitored as well. This process could help determine whether or not the catch limit is likely to cause undesirable effects on predators in any of the predator units. In this way, it is possible to determine, well in advance of the catch limit being reached, whether or not local restrictions on harvesting are necessary, as well as the overall requirements for the monitoring program.

Résumé

Les auteurs examinent, dans le cadre de la gestion du krill antarctique, les principes et l'approche qu'il convient de suivre pour définir des unités de gestion à petite échelle qui tiennent compte des besoins des prédateurs. Ils présentent ce qui servira de base théorique à l'examen des échelles des unités de gestion, à savoir l'intégration des populations locales des espèces exploitées, les secteurs d'alimentation des prédateurs, les lieux de pêche et les effets potentiels de l'environnement, tels que l'océanographie et la structure de la métapopulation des espèces exploitées. Pour intégrer ces éléments, il faut concevoir deux types d'unité : l' «unité d'exploitation», à l'échelle de la métapopulation des espèces exploitées, et l' «unité des prédateurs», qui ne doit pas nécessairement être un écosystème relativement autonome, mais qui doit être suffisamment indépendant pour que la pêche n'y affecte pas par inadvertance les prédateurs contrôlés dans d'autres unités. La région de l'Atlantique Sud (zone 48) sert d'exemple pour démontrer comment définir les unités des prédateurs. Le modèle conceptuel qui en est dérivé sert ensuite à la formulation d'une approche du développement des pêcheries visant des espèces de proies, notamment le krill, dans d'autres unités d'exploitation. Les auteurs examinent la manière dont les unités des prédateurs pourront servir, dans le Programme de contrôle de l'écosystème de la ccamlr (cemp), à faciliter la formulation d'avis stratégiques sur les effets de la pêche. En général, l'acquisition précoce d'informations sur la répartition des populations locales de krill et les densités potentielles de prédateurs à la recherche de nourriture au sein d'une unité d'exploitation (c.-à-d. l'abondance des prédateurs, la répartition des colonies et le secteur d'alimentation) permettra de délimiter les unités des prédateurs et d'évaluer le rendement annuel à long terme. Selon les auteurs, une pêcherie pourrait à ses débuts se concentrer dans quelques unités de manière à ce que l'intensité de pêche relative dans chaque unité soit équivalente (mais pas forcément égale) à l'intensité prévue dans toutes les unités, une fois la limite de capture atteinte. D'autres unités dans lesquelles aucune pêche n'aurait eu lieu pourraient également être contrôlées. Ce processus pourrait aider à déterminer si la limite de capture risque d'avoir des effets nuisibles sur les prédateurs d'une des unités des prédateurs. Il est ainsi possible de déterminer, bien avant que la limite de capture ne soit atteinte, si des restrictions locales de l'exploitation sont nécessaires, et d'identifier les exigences globales du programme de contrôle.

Резюме

В статье обсуждаются принципы и подход, необходимые для разработки мелкомасштабных единиц управления с учетом потребностей хищников в процессе управления промыслом антарктического криля. Приводится теоретическое обоснование для рассмотрения масштабов единиц управления, включающих интеграцию локальных популяций промысловых видов, ареалов кормления хищников, промысловых участков и возможного воздействия окружающей среды, в т.ч. океанографии и метапопуляционной структуры промысловых видов. С интеграцией этих компонентов связано 2 типа единиц: «единицы промысла», которые имеют масштаб метапопуляций промысловых видов, и «единицы хищников», которые не обязательно являются относительно автономными экосистемами, но должны быть достаточно независимыми, чтобы промысел в такой единице не мог случайно повлиять на хищников, мониторинг которых ведется в других единицах. Для иллюстрации определения единиц хищников используется район южной Атлантики (Район 48). Полученная концептуальная модель затем используется, чтобы сформулировать подход к развитию промысла потребляемых видов, особенно криля, в других промысловых единицах. Обсуждаются пути возможного использования единиц хищников для выработки стратегических рекомендаций, касающихся воздействия промысла, в рамках Программы АНТКОМа по мониторингу экосистемы (CEMP). В целом, раннее получение информации о распределении локальных популяций криля и потенциальной плотности кормления хищников с какого-то промыслового участка (т.е. численности хищников, распределении колоний и ареале кормления) позволит определить единицы хищников, а также провести оценку долгосрочного ежегодного вылова. Предлагается, чтобы ранние стадии развития промысла были сконцентрированы на небольшом количестве участков так, чтобы относительная интенсивность промысла на этих участках была эквивалентна, но не обязательно равна, интенсивности, ожидаемой на всех участках при достижении ограничения на вылов. Также может проводится мониторинг единиц, в которых промысел не велся. Это позволит определить, может ли ограничение на вылов иметь нежелательные последствия для хищников на участках «хищников». Таким способом можно определить, задолго до достижения ограничения на вылов, нужны ли локальные ограничения на вылов, а также общие требования программы мониторинга.

Resumen

Este trabajo trata sobre los principios y enfoque necesarios para el desarrollo de las unidades de ordenación en pequeña escala que toman en cuenta las necesidades de los depredadores en la ordenación de la pesquería del kril antártico. Se presenta un fundamento teórico para considerar la escala de las unidades de ordenación que integra las poblaciones locales de especies explotadas, las zonas de alimentación de los depredadores, los caladeros de pesca y las posibles influencias del medio ambiente, incluida la oceanografía y la estructura metapoblacional de las especies explotadas. La integración de estos componentes se relaciona con dos tipos de unidades diferentes: las 'unidades de explotación', a la misma escala de la metapoblación de las especies explotadas y las 'unidades de depredadores', que no se refieren necesariamente a un ecosistema autosuficiente, pero sí deben ser lo suficientemente independientes como para sostener la pesca en esa unidad sin que los depredadores estudiados en otras unidades se vean afectados. La región del Atlántico sur (Área 48) ha sido utilizada para ilustrar cómo se definen las unidades de depredadores. El modelo conceptual derivado es utilizado luego para formular una estrategia de desarrollo de las pesquerías de las especies presa, en particular, del kril, en otras unidades de explotación. Se considera cómo se podría utilizar las unidades de depredadores para que el programa de seguimiento del ecosistema de la CCRVMA (CEMP) pueda brindar información estratégica sobre las consecuencias de la pesca. En general, la obtención temprana de información sobre la distribución de las poblaciones locales de kril y la posible densidad de depredadores en actividades de alimentación dentro de una unidad de explotación (esto es, abundancia de depredadores, distribución de colonias, y radio de alimentación) ayuda a circunscribir las unidades de depredadores y a evaluar el rendimiento anual a largo plazo. Se propone que en su etapa inicial la pesquería se concentre en un pequeño número de unidades de forma que la intensidad relativa de la pesca en esas unidades sea equivalente, aunque no necesariamente igual, a la intensidad prevista en todas las unidades al alcanzarse el límite de captura. También se podrían controlar otras unidades que no están siendo explotadas. Con este proceso se podría determinar si el límite de captura afectaría negativamente a los depredadores de una unidad cualquiera de depredadores. De esta manera, se puede determinar mucho antes de alcanzar el límite de captura si se necesita aplicar restricciones locales en la explotación, así como los requisitos generales del programa de seguimiento.

Keywords: ecosystem approach, krill fisheries, krill predators, management units, scales of units, conceptual model, CCAMLR

INTRODUCTION

The ecosystem approach to managing fisheries in the Southern Ocean requires that the needs of predators (dependent species) be taken into account when setting fishing controls on harvested species. CCAMLR has adopted specific objectives for the implementation of a precautionary approach to krill fisheries within this framework, but is yet to develop strategies for directly taking account of the needs of predators in an ongoing management framework for a fully developed fishery (Constable et al., 2000).

CCAMLR currently manages its fisheries by setting catch limits for statistical subdivisions of the CCAMLR Convention Area. In the case of the fishery for Antarctic krill (*Euphausia superba*), the catch limits have been set for large statistical subareas or for entire oceanic regions, such as for the South Atlantic (FAO Statistical Area 48). In establishing the catch limit for Area 48, CCAMLR recognised the need to subdivide this into smaller areas to avoid localised effects on predators (Conservation Measure 32/X) (CCAMLR, 1991; Watters and Hewitt, 1992). If the whole catch limit for krill was taken from within the foraging range of a few predator colonies, then the fishery could have a substantial effect on those colonies. The issue of a subdivision of the catch limit has not been resolved, despite early consideration of the options that could be used to provide for an effective subdivision (Watters and Hewitt, 1992; Everson, 2000; Miller and Agnew, 2000). With the recent revision of the precautionary catch limit for krill, CCAMLR has requested that the krill catch limit be subdivided in Area 48 to better account for the needs of predators (SC-CAMLR, 2000a).

An important issue to be considered in this process is how the respective scales of the ecological dynamics of predators and the krill population can be matched with the larger scale of the fishery (see Schneider, 1994 for a theoretical discussion). The aim of this paper is to discuss the issues of scale and how these may be integrated to form the principles underpinning the development of small-scale management units, and to recommend an approach for their implementation.

WHAT IS A MANAGEMENT UNIT?

Effective management units are usually considered to be self-contained areas in which a fish stock, fishery and ecosystem interact, with little interference from external factors. These can be viewed in a number of ways, from the perspective of each harvested species, each dependent species, their habitats and the fishery. In all cases, the principles governing the size of the unit are the same, although the terminology used may be slightly different.

The basic principles for defining a unit are most easily explored in terms of the structure of animal populations. A group of animals that are continuously distributed throughout a favourable habitat is called a population, the boundary of the population being governed by the boundary of the habitat. Often, the edge of the habitat is graded in quality resulting in diminishing density of the population at the periphery (Figure 1a). If the habitat is fragmented then the population is fragmented. The species may then be considered to comprise a number of populations (Figure 1b). A population is considered isolated when there is negligible exchange (immigration/emigration) between populations. Its existence is then dependent on reproduction by individuals within the population. If they remain isolated then each of those populations would be a self-sustaining unit. If exchange occurs between areas then this would be expected to be more likely between nearby areas than distant areas (Figure 1c). An area with a well-mixed group of individuals is known as a 'local population'. A collection of local populations with some exchange between them is known as a 'metapopulation' (Andrewartha and Birch, 1984).

Defining a discrete metapopulation is difficult, particularly for marine species. For benthopelagic species, a whole continental shelf may define a metapopulation. For pelagic species, metapopulations may be constrained within large oceanographic features (frontal zones, eddies, gyres). Local populations in these areas are considered to be areas where discrete and predictable concentrations of abundance are observed.

For a dependent species, a unit is defined not only in terms of identified local populations, such as land-based colonies, but also in terms of the relative independence of foraging areas (Figure 2). This latter point is important because if two predator colonies feed in the same area then they are effectively in the same 'foraging unit'. If a single local population of prey exclusively supports a number of colonies made up of different predator species then this would be a discrete unit. However, some predator species may be wide-ranging foragers of many local populations of prey (e.g. whales), while others may be very local, not utilising much of the area of a local prey population.

For fisheries, the unit is an area within which vessels concentrate their activities, i.e. a 'fishing ground' (Figure 3). A fishing ground is an area in which the long-term economic efficiency is expected to be greatest (from one season to another). The ability to reduce the size of the fishing ground further will be dictated by the economic costs that might be involved. Movement from one fishing ground to another will have an economic cost. The fishing ground may be within the area inhabited by a local population of the harvested species or may encompass a number of local populations, depending on the scale of operations relative to the scale of the populations.

INTEGRATING DIFFERENT CHARACTERISTICS INTO MANAGEMENT UNITS

Ideally, a management unit is one in which the predator–prey system is relatively independent of other systems or, at least, the links between the units are predictable. By necessity, two types of unit need to be identified because the scales will inevitably be different between areas of harvested species populations and foraging ranges of predators. The first type of unit is a larger-scale area circumscribing the managed population of the harvested species, referred to below as the 'harvesting unit'. The second type is smaller and comprises the relatively independent predator–prey–fishery system, referred to below as the 'predator unit' (Figure 4). Conceivably, the size of the harvesting and predator units may be the same but this is unlikely. The scales of the fishing grounds will not impact on the initial designation of the predator units but they will influence how those units will be used in a management procedure for krill (see below).

The harvesting unit is likely to comprise a number of fishing grounds and will most likely circumscribe a metapopulation of the target species, e.g. Antarctic krill (*E. superba)* is assessed at the scale of the South Atlantic. This is the scale at which sustainability of fishing on the stock is assessed, such as by using the krill yield model to determine a long-term annual yield for krill (see Constable et al., 2000 for review).

The predator unit is constrained by the spatial location and extent of the independent predator foraging areas and the location and extent of the local populations of prey. If the foraging areas are contained within the range of the local population of prey then the spatial extent of the local prey population is the constraining feature.

The scale of predator units is such that the harvesting strategy within each of these units may differ depending on the requirements for achieving ecosystem objectives as well as requirements for monitoring the effects of fishing. CCAMLR has agreed to maintain the ecosystem monitoring program for the latter purpose. Preferably, fishing in a designated predator unit should not inadvertently affect predators being monitored in other units. If this is not possible then the nature (not necessarily magnitude) of the effect of a fishery in one area on predators in another area needs to be predictable, e.g. a reduction in krill in one area leads to a reduction in its availability in another. Consequently, transport of krill need not be a defeating feature of the system if the movement is predictable in a particular direction.

It is important to consider the potential differences in the extent of foraging by different species. Figure 4 illustrates the potentially all-encompassing foraging ranges of whales; this could also be applied to other species, such as flying birds. In such circumstances, predator units may be better specified in terms of a subset of predators, such as land-based predators, particularly if they are the parts of the system most easily monitored, while taking account of the uncertainties associated with the potential influence of wider-ranging predators.

USING MANAGEMENT UNITS TO MANAGE ANTARCTIC FISHERIES: INDICATORS AND FEEDBACK MANAGEMENT

Defining Predator Units: Small-scale Features within Harvesting Units

The South Atlantic region (Area 48) provides the best illustration of how to define predator units because it is the region for which the greatest knowledge is available. As such, it provides an opportunity for examining how the effects of krill fishing might be assessed in this region and, therefore, provides guidance as to how the development of krill fishing should be monitored in other regions, which have received little attention by krill fishers at this stage.

Models of the oceanography and distribution of krill in the South Atlantic have been published over the last decade, with the most recent analysis arising from the CCAMLR 2000 Synoptic Survey of Krill in Area 48 (SC-CAMLR, 2000b). Ichii and Naganobu (1996) show that for the South Shetland Islands region the dominant current is the west–east flow of the Antarctic Circumpolar Current (ACC) to the north of the shelf break. Over the shelf area, the flow is reversed. Hofman et al. (1998) present a model of the dominant flows in the South Atlantic with potential transport of krill from the Antarctic Peninsula to South Georgia and beyond. Ichii and Naganobu (1996) estimate from their studies that krill could be transported to South Georgia and to the South Orkney Islands from the South Shetland Islands in as little as 110 to 120 days and 85 days respectively. Siegel (2000) describes the seasonal movement of krill between offshore and inshore waters of the Antarctic Peninsula and how this will influence the movement of krill in the ACC. This adds to the complexity of the metapopulation dynamics of the region, with more work needed to quantify the vectors of net transport between the local populations in the region.

Despite the uncertainties in krill transport, there are recognised areas where krill is expected to aggregate based on empirical observations, including the Antarctic Peninsula (Kawaguchi et al., 1997; Siegel et al., 1997; Siegel, 2000), the South Orkney Islands (SC-CAMLR, 2000b) and South Georgia (Trathan et al., 1998; Brierley et al., 1999). In the Antarctic Peninsula, krill is expected to aggregate in the Bellingshausen Sea/ southwestern Antarctic Peninsula, north of King George and Livingston Islands, and Elephant Island (Kawaguchi et al., 1997; Siegel et al., 1997; Siegel, 2000). These may contain the equivalent of five local populations with net transport of krill in a west-to-east direction. Importantly, these areas could be considered separate small-scale areas if the vector of transport is relatively predictable from one year to another. Eventually, quantification of those vectors would help in developing models of the spatial dynamics of krill in the region and assist in interpreting results from the CCAMLR Ecosystem Monitoring Program (CEMP).

General foraging areas for land-based predators in the region have been described in Everson and de la Mare (1996). These areas are contained within 125 km of the coastline around the island groups and the Peninsula.

The fishing grounds in the region are well described for South Georgia (Trathan et al., 1998) and the South Shetland Islands (Kawaguchi et al., 1997) and plots of the areas of fishing activity are available in the annual CCAMLR *Statistical Bulletin*. To illustrate the general location of these grounds, an analysis was undertaken of fine-scale catch data for Area 48 using the historical dataset that is complete, i.e. 1988–2000. The total catch of krill over this period in each fine-scale area (0.5° latitude x 1° longitude) is shown in Figure 5. This indicates that the fishing grounds are consistent with the areas considered to contain local populations of krill. This indicates also that very little fishing has occurred on the local population in the southwestern Antarctic Peninsula west of 62°W, probably because of ice conditions.

Apart from the subdivision in the vicinity of the Antarctic Peninsula, the fishery information illustrated in Figure 5 indicates that the South Orkney and South Georgia regions could be further divided. The South Orkney area could be divided into east and west at 46°W and the South Georgia fishery could be divided into east and west at 37°W (see Trathan et al., 1998 for a more detailed analysis for South Georgia).

The relative importance of the different fishing grounds provides some indication of the relative importance of the different local populations of krill to the fishery and the potential for competition with predators. The fine-scale area data were analysed to determine how much fishing occurred in the predator foraging areas defined by Everson and de la Mare (1996). Very few catches occurred outside these areas, indicating that the current fishery occurs almost entirely within the foraging ranges of land-based predators.

Using the fishery information as an approximation for local krill populations and combined with the land-based predator information, a conceptual model of predator units can be formulated for the South Atlantic area as shown in Figure 6. Such a model could be further refined by analysing available data on local krill distributions and updated predator foraging information.

The potential overlap between the fishery and predators throughout a year may alter as a result of changing fishing patterns during the year. Figure 7 shows the relative contributions of the different areas in Figure 6 to the total catch in each season, from winter 1987 to autumn 2000, using the fine-scale data. The results show that the King George and Livingston Island area has been fished consistently since 1988 and is the most important area in the current fishery. The South Orkney and South Georgia regions have generally declined in importance since 1991, although they have been important in some years since then. In this analysis, Elephant Island appears relatively unimportant in the fishery. The differentiation between the eastern and western parts of South Orkney and South Georgia areas is evident, with the important areas being to the west and to the east respectively. Importantly, these results generally show the persistence of the krill fishery in the southern areas during autumn and winter periods since autumn 1996 and winter 1998 respectively. This has increased to the extent that the autumn fishery around the South Shetland Islands is dominating the annual catch. This is most likely due to reduced ice cover at those times (see Constable et al., in press).

INDICATORS AND FEEDBACK MANAGEMENT

Within a harvesting unit a fishery will be expected to meet the objectives of CCAMLR. The potential for localised effects on predators of harvested species is great unless the harvest controls include more than just a total allowable catch for a harvesting unit (Watters and Hewitt, 1992). In 2000, CCAMLR adopted a subdivision of the catch limit in Area 48 pending further analyses and review of appropriate catch controls in localised areas. The strategy (in space and/or time) for subdividing the catch needs to: (i) reduce the potential for undesirable local effects on predators; and (ii) ensure that, if such effects do arise, they can be detected in time to take remedial action. In the latter case, CEMP has been developed to indicate when predators are being affected by fishing.

The complexity of processes within and connecting the predator units identified in Figure 6 would suggest that attention needs to be given to specifying what information might reliably indicate whether or not fishing is affecting predators. While the statistical approaches used in CCAMLR need to account for the likelihood of occurrence of specific outcomes, the structural arrangement of the monitoring program can still lead to errors in decisions about the types of adjustments to harvest strategies that might be required. For example, Type I errors can arise when it is concluded that harvesting needs to be constrained (in catch, space or time) because of a decline in predators even though the decline may have arisen from causes other than krill availability. Such a conclusion could be drawn in the absence of contrasting information from areas unaffected by fishing.

Alternatively, Type II errors could arise when it is concluded that harvesting need not be constrained even though krill availability may have altered. This could occur if harvesting was occurring in one predator unit while monitoring was occurring in a different predator unit not affected by fishing.

Establishing a framework in CEMP to strategically acquire similar information from a number of different predator units will help discriminate between the effects of the environment and the effects of fishing. One way of achieving this might be to establish different fishing intensities relative to predator foraging densities in different predator units. This could be used to provide the signals necessary to adjust local catch limits before problems arise, such as in a feedback management procedure (Constable, 1992).

CONCLUDING REMARKS: DEVELOPING A GENERAL APPROACH TO SUBDIVIDING HARVESTING UNITS

The complexities outlined for Area 48 illustrate that a number of steps may need to be taken during the early phases of fisheries on prey species, in order that the development of the fishery and the maintenance of ecological relationships between harvested species and predators can be taken care of simultaneously.

The early acquisition of information from within a harvesting unit on the distribution of local populations of krill and the potential foraging density of predators on these local populations (i.e. abundance of predators, distribution of colonies and general foraging range) will provide the means for circumscribing smaller-scale predator units as well as undertaking an assessment of long-term annual yield.

These predator units can then be used to establish strategic monitoring programs which can be carried out in a number of selected units rather than monitoring throughout the harvesting unit. The early development of the fishery could be concentrated in a small number of units, which would depend on the scales of economic efficiencies for the fishery, to the extent that the relative fishing intensities in those units are equivalent, although not necessarily equal, to the intensity expected across all units once the catch limit had been reached. Other units in which fishing was not occurring could be monitored as well. This process could help determine whether or not the catch limit is likely to cause undesirable effects on predators in any of the predator units.

In this way, it may be possible to determine whether or not local restrictions on harvesting are necessary well in advance of the catch limit being reached; likewise for determining the overall requirements for the monitoring program. It should be noted that the design of this approach will require careful preparatory work to take account of potential linkages between predator units. For example, movement of krill through the South Atlantic may constrain the utility of predator units in this experimental approach. Similarly, the economic constraints arising from restricting the fishery to particular areas will need to be evaluated. Such a process could be undertaken before the trigger levels in existing conservation measures are reached, thereby ensuring that information will be available to review the subdivision of the catch limits in harvesting units.

In conclusion, the process of establishing predator units will provide the opportunity for understanding how the dependent species in a harvesting unit can be monitored effectively. It may be best to ensure that harvesting is concentrated in smaller predator units rather than in areas where fishing may affect other species but for which no effective monitoring can be undertaken. This is potentially a key consideration in achieving the objectives of CCAMLR for both land-based and sea-based predators.

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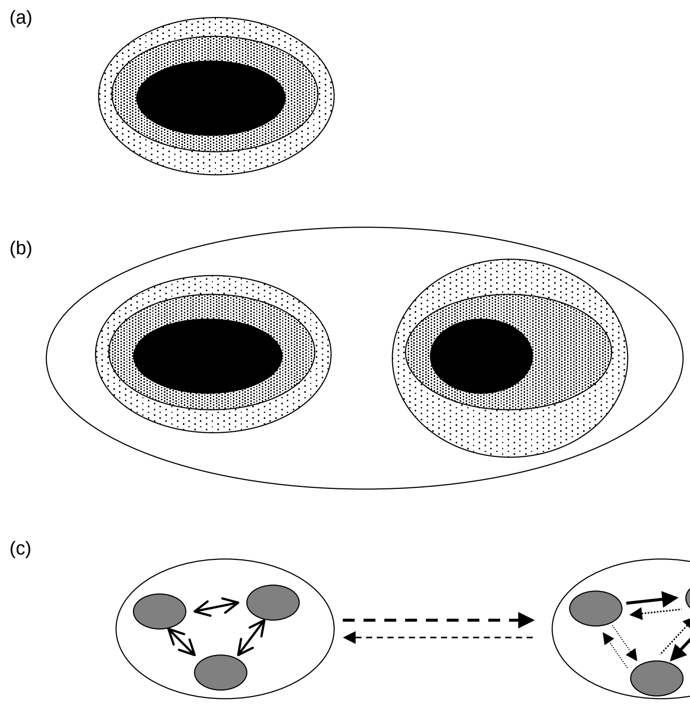


Figure 1: Diagrams of population structure. (a) Single population with greatest densities shown in black, reduced density with reduced stippling, and a clear boundary at the edge of the habitat. (b) Two separate populations. (c) Two metapopulations with three local populations in each: the left hand population has exchange in both directions between each of the local populations; the right hand population has one local population (top left) acting predominantly as a source population with flow of individuals mostly in a single direction to a sink population (bottom); exchange between the metapopulations is mostly in one direction from left to right.

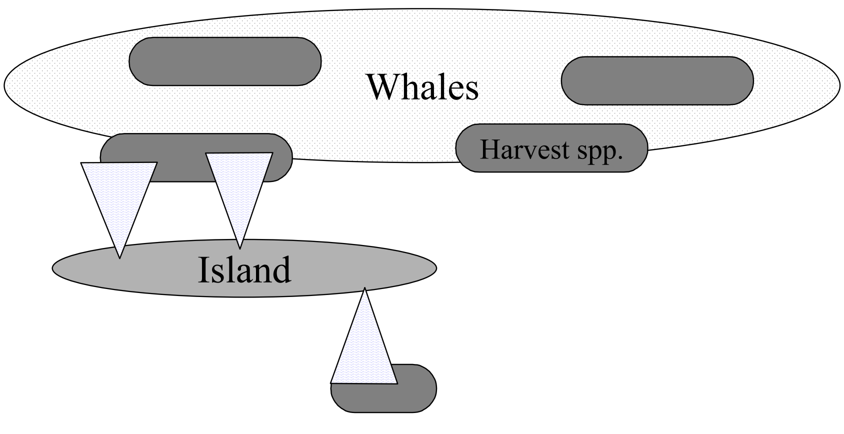


Figure 2: Schematic diagram showing possible relationships between foraging areas of land-based predators (triangles) and sea-based predators (e.g. whales) on local populations of a harvested species (dark truncated ovals). The bottom triangle and local population of the harvested species shows a predator–prey system independent of the top system.

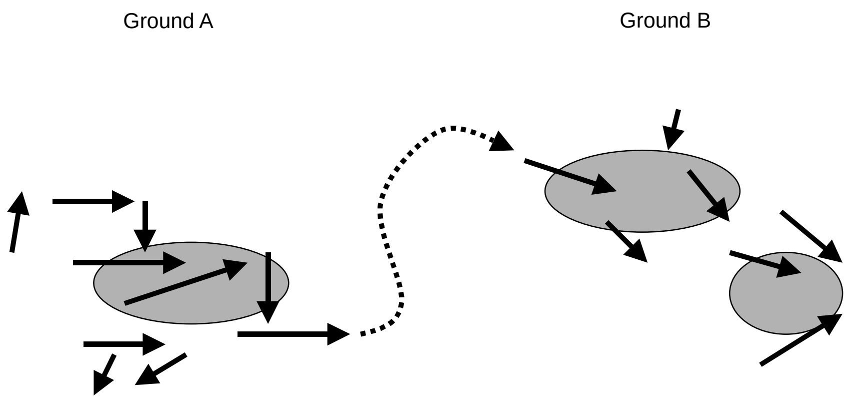


Figure 3: Schematic diagram showing fishing grounds as concentrated areas of fishing activity on one or more local populations. The number of local populations in a ground will depend on the scale of the fishing activity compared to the spatial extent of a local population. Arrows indicate fishing vessel behaviour, e.g. individual hauls.

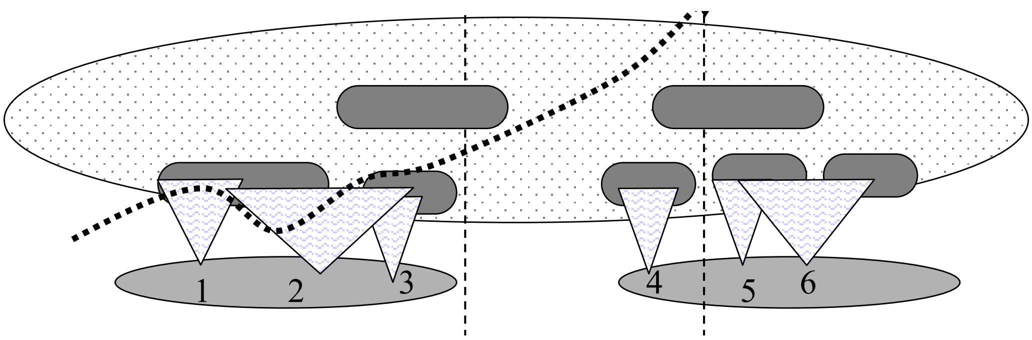


Figure 4: Schematic diagram showing the structure of predator units and the relationship between predators (land-based – triangles; sea-based, e.g. whales – dotted oval), local populations of harvested species and a fishery (bold dotted line). Colonies of predators that can be monitored are numbered. The vertical dashed lines separate three predator units (see text for explanation).

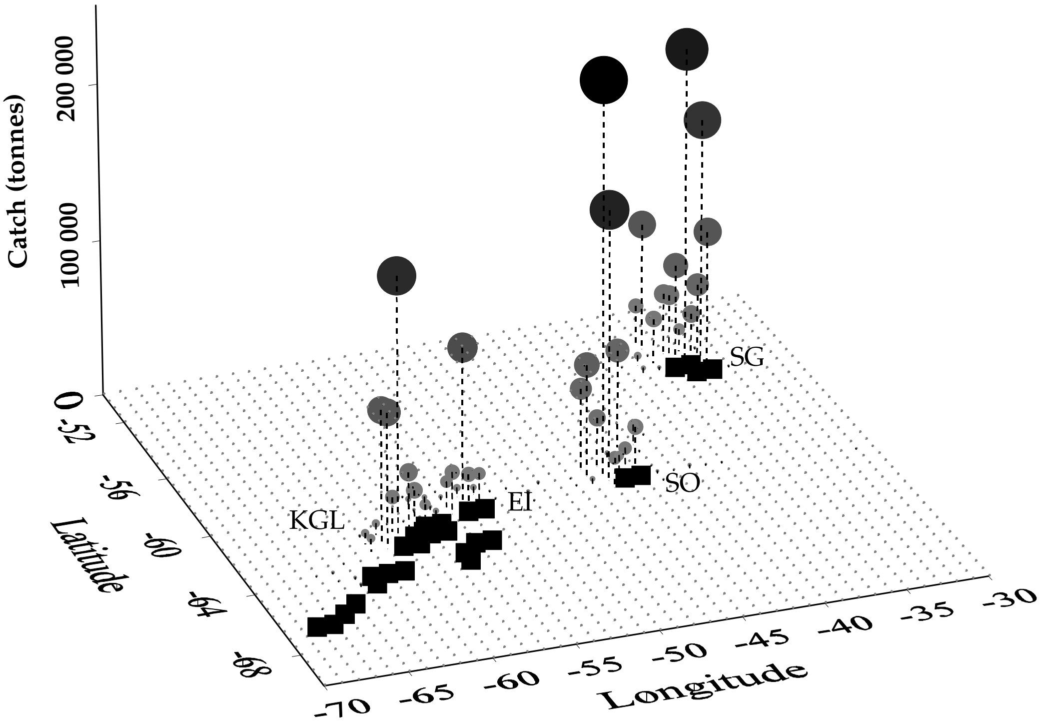
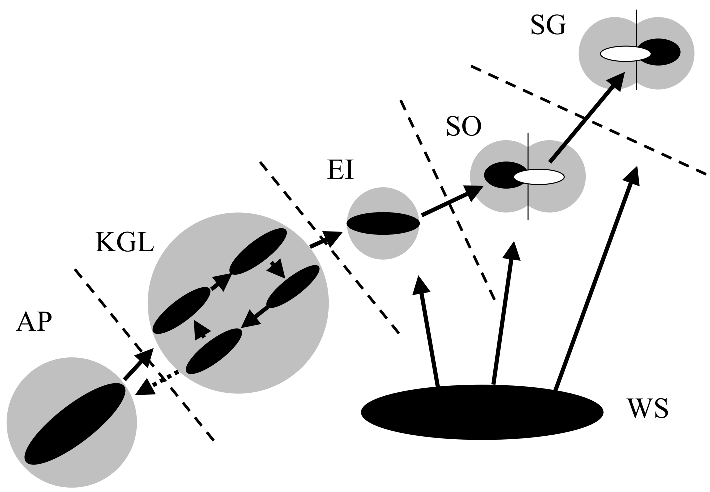


Figure 5: Total catch of krill (tonnes) between the 1988 and 2000 split-years in each fine-scale area (0.5° latitude x 1° longitude) in the South Atlantic (CCAMLR Area 48). Shaded circles are proportional to the size of catch. Dashed lines are vertical bars relating each shaded circle to the coordinates of the fine-scale area. Black squares are fine-scale areas in which land is present. KGL = King George and Livingston Islands; EI = Elephant Island; SO = South Orkney Islands; SG = South Georgia.



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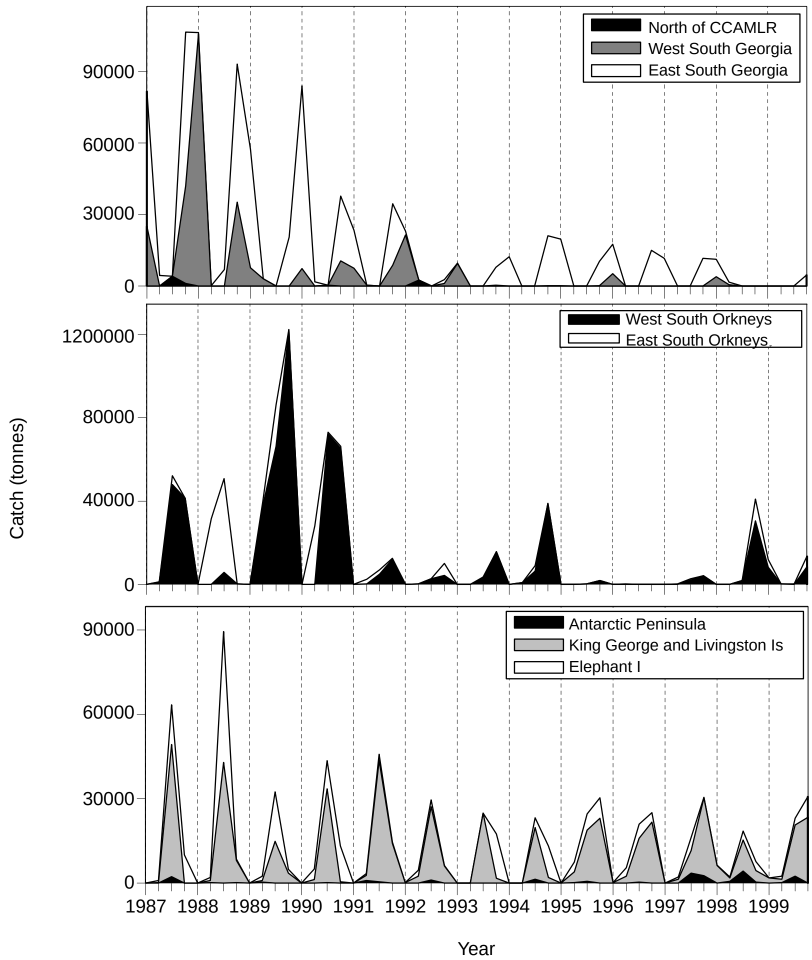

Figure 7: Total krill catch (tonnes) for each statistical subarea in the South Atlantic region for each season from July 1987 to June 2000: Subarea 48.3 (top panel), Subarea 48.2 (middle panel) and Subarea 48.1 (bottom panel). The season marked by each title year and the vertical dashed lines is winter (July–September). Each check mark following a title year represents consecutive seasons of spring (October–December), summer (January–March) and autumn (April–June). Catches are broken down in each season and subarea to show catches in each of the fishing areas described in the text.

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Рис. 7: Общий вылов криля (т) по статистическим подрайонам южной Атлантики за каждый сезон с июля 1997 по июнь 2000 г.: Подрайон 48.3 (верхний рисунок), Подрайон 48.2 (средний рисунок) и Подрайон 48.1 (нижний рисунок). Пометка для каждого года и вертикальная пунктирная линия соответствуют зиме (июль–сентябрь). Каждая отметка за годом представляет последовательные сезоны: весну (октябрь–декабрь), лето (январь–март) и осень (апрель–июнь). Уловы разбиты по всем сезонам и подрайонам, чтобы показать вылов в каждом районе промысла, описанном в тексте.

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