THE POLICING OF BIOMARINE RESOURCES IN THE SOUTHERN OCEAN

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Scott Polar Research Institute
University of Cambridge.

15 June 1994
Opposite page: The patrol vessel *Falklands Desire* passes Navy Point in the Falklands Islands. (Photograph courtesy S J Couch)
The views expressed within this thesis are those of the author, and do not necessarily reflect Government policy or judgement regarding the subject material.
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CONVENTIONS AND SYMBOLS USED IN THE TEXT

The use of nautical miles and knots remains common practice in the maritime world, aviation, and marine law. This convention has been retained other than for some of the calculations, where Systeme International d’Unites units are more appropriate. Scientific notation has been used to express large and small quantities conveniently. The use of indices of negative sign indicates proportion or rate, for example, 10 m^2, (10 per square metre), and 5 yr^-1 (5 per year).

The symbol '*' denotes multiplication.

The following abbreviations have been used. They are presented in alphabetical order, for ease of reference:

**Units of measure and navigation**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Centigrade</td>
<td></td>
</tr>
<tr>
<td>dB</td>
<td>decibels, where 10 times the common logarithm of the ratios in question have been used</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>East</td>
<td></td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
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</tr>
<tr>
<td>g</td>
<td>gravitational acceleration</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>giga</td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>High frequency</td>
<td></td>
</tr>
<tr>
<td>hr</td>
<td>hour</td>
<td></td>
</tr>
<tr>
<td>Hz</td>
<td>Herz</td>
<td></td>
</tr>
<tr>
<td>in</td>
<td>inches</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Joules</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Kelvin</td>
<td></td>
</tr>
<tr>
<td>km</td>
<td>kilometres</td>
<td></td>
</tr>
<tr>
<td>kts</td>
<td>knots</td>
<td></td>
</tr>
<tr>
<td>kW</td>
<td>kilowatts</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>mega</td>
<td></td>
</tr>
<tr>
<td>mm</td>
<td>millimetres</td>
<td></td>
</tr>
<tr>
<td>mW</td>
<td>milliwatts</td>
<td></td>
</tr>
<tr>
<td>nm</td>
<td>nautical miles</td>
<td></td>
</tr>
<tr>
<td>Pa</td>
<td>Pascal</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>South</td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>tons</td>
<td></td>
</tr>
</tbody>
</table>
UHF = Ultra high frequency
VHF = Very high frequency
yds = yards
yr = year

Other abbreviations

GRT = gross registered tons
MTI = moving target indication
μ = Mu (micro-)
SLAR = Side-Looking Airborne Radar
SECTION I: SUMMARY

The Southern Ocean constitutes some 22% of the world ocean, and has some of the worst climatic conditions on the planet. Historically, marine biota have been one of the most important benefits derived from the Antarctic. The history of living resource utilisation in the region is a record of pillage, with market forces as the only constraint. Recently, this has changed, with the emergence of international agreements and public demand for conservation.

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is unique both in the ecosystem approach it takes to the management of the fisheries and living resources, and in the lineage of the Antarctic Treaty System from which it stems. Despite its endeavours within the purview of treaty law, its greatest powers may derive from the coincidence of the richest fishing grounds and the Exclusive Economic Zones (EEZs) surrounding the peri-Antarctic islands possessed by member states.

Despite the range of approaches available to address the problems of biomarine resource policing, no single approach emerges as a complete and cheap solution. The most promising surveillance technique is satellite remote sensing, utilising synthetic aperture radar. At present, the most economical existing technology for surveillance around the peri-Antarctic islands is light aircraft, and on the high seas, onboard inspectors representing CCAMLR interests. The most economical patrol vessels are likely to be those purchased outright as working vessels, and converted to government use.
SECTION II: INTRODUCTION

Despite extravagant claims for prolific resources in the Antarctic, the principal benefits which have been derived from the region to date are marine biota, and scientific information. This has been the case throughout the history of Man’s involvement in the Antarctic. Today the industrial exploitation of marine mammals has given way to the harvesting of fish, crustacea and cephalopods, while the heroic age of exploration has been replaced by an era of scientific investigation and ecological awareness. A trend towards an increase in tourism may indicate an industry of great future value. However, the value of the Southern Ocean fishery is potentially enormous, and at present there is little to indicate that it will be replaced as the premier resource of the region.

Estimates of the maximum sustainable yield of biomarine resources in the Southern Ocean made a decade ago suggested that although the portion of the world sea surface within the Antarctic Convergence constitutes only 10% of the whole, it could rival the production of the remainder, particularly in krill (Knox, 1983, p.21). These estimates for sustained yield have not been realised, and if the Southern Ocean is to be preserved as a source of protein, its living resources will require careful husbandry.

The availability of this resource is of particular relevance during the present period of human history. The division of the numerical majority of the best fishing grounds amongst the Exclusive Economic Zones of the world’s nations, and the economic repercussions of the collapse of the Soviet Union have made the availability of a major fishery particularly desirable; albeit a fishery in a remote and environmentally hostile
ocean. There is spare capacity amongst the world’s fishing fleets, and great profits to be made. At the same time, the Southern Ocean ecosystem is particularly vulnerable to over-harvesting.

The history of marine resource harvesting in the Antarctic is essentially one of plunder. Some species have been commercially exploited to the threshold of extinction. At the same time, the legal circumstances of the Southern Ocean are unique and give cause for hope that the classical repetition of history may be thwarted. The majority of Antarctic Treaty signatories have acceded to the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). This revolutionary agreement takes an ecosystem approach to scientific resource management, and features many of the nations with distant water fishing interests in the region. Perhaps more significantly, some states with claims to sovereignty over peri-Antarctic islands, and who police the associated EEZs, are also members of CCAMLR.

Nonetheless, the Southern Ocean is largely a high seas region, and fishing on the high seas is an ancient right. The question of adequate policing and the protection of these resources for the benefit of the world community, whether within sovereign waters or on the high seas, remains an important one. It is this issue to which this thesis is addressed.

The biomarine resources which are the subject of this study include all species indigenous to the Southern Ocean which may be considered to be commercially significant human food. Mention will also be made of protein sources of commercial value as livestock feed. A broad approach has been taken to the evaluation of techniques
suitable for the enforcement of measures designed to protect edible living resources in the Southern Ocean ecosystem. The definition of those resources is also deliberately broad, and the author neither advances nor challenges arguments concerning the use of particular species as a source of food.
SECTION III: OCEANOGRAPHIC OVERVIEW OF THE SOUTHERN OCEAN

In order to understand the unique nature of the Southern Ocean ecosystem, and the problems faced when attempting to police its biological resources, it is necessary to consider the oceanography and climate of the region. Although historically cartographers and authors have for convenience regarded the region as southern extremities of the Atlantic, Pacific and Indian Oceans, treatment of the Southern Ocean as a single geographical entity is essential when describing the area from the viewpoint of polar oceanography. This is also true from the perspective of biological oceanography.

The Ocean is flanked to the south by the continent of Antarctica. For the purposes of this study, the northern extremity of the ocean will be that adopted by Tchernia, the hydrological limit defined by the Subtropical Convergence, or STC (Tchernia, 1980, p.44). The STC is a zone of hydrological discontinuity marked by a change of surface temperature of 15°C to 12°C during passage from north to south. Its position varies from season to season between 38:00°S and 42:00°S. Although well defined in the South Atlantic, Indian and West Pacific Oceans, the position of the STC is less easily determined in the eastern Pacific (Figure 1) (Tchernia, 1980, op. cit.).

As defined, the Southern Ocean is a circumpolar phenomenon with a width of 26°-30° of latitude - 1600 to 1800nm. Within the boundary of the STC, its surface area is some $77 \times 10^6 \text{ km}^2$, 22% of the total of the world ocean. Although bounded to the north by three continental landmasses, only South America is sufficiently adjacent to form any kind
Figure 1: Ocean fronts in the Southern Ocean. (Deacon, 1984, p.2)
of strait - the Drake Passage, which in vertical section is 420nm between the 500m isobaths (Tchernia, 1980, p.45).

The three principal basins of the Antarctic oceanic ring average 4000 to 6500m in depth, and are separated by ridges (Figure 2). The Southern Ocean features some of the most bleak and isolated islands in the world. As with most mid-ocean islands, these are volcanic in origin. Many of the most remote were discovered in the eighteenth century by French mariners, whose names they still bear - Bouvet, Marion, Crozet, Kerguelen. Wet, cold, and frequently beset by fog and storms, these islands show no evidence of having ever supported an indigenous population (Tchernia, 1980, op. cit.). However, they are of particular significance to the commercial distant water fisheries in the area, and constitute vital habitats for the many birds and marine mammals which require sites for breeding in a polar region offering meagre ice-free land to the competing avian and amphibious biota.

Many of the properties of the Southern Ocean, including the prolific nature of its biota, and consequently its fisheries, are the indirect result of the climate. Westerly winds are features of both hemispheres (Figure 3). In the Southern Ocean, they result in the most obvious feature of the surface circulation - the West Wind Drift, or Antarctic Circumpolar Current (Figure 4). This massive net transport of water continuously circles the globe with a mean speed of under 0.5 kts (Deacon, 1984, p.88). The flow interacts with other water masses, and impinges on topographic features in its path, elevating nutrients to shallow depths and stimulating primary production when sufficient sunlight
Figure 2: Bathymetry of the Southern Ocean. (Tchernia, 1980, p.48).
Figure 3: Mean zonal wind speeds m s\(^{-1}\). (Barry and Chorley, 1992, p.127).
Figure 4: Surface circulation in the Southern Ocean. (Tchernia, 1980, p.57).
becomes available for the phytoplankton. It is largely as a result of this process that the peri-Antarctic islands have become the focus of fishing activity in the maritime Antarctic.

The Southern Ocean features a concentric system of frontal zones separating various water masses. The boundary of the eastward and westward current systems forms the Antarctic Divergence, at which the physical forces associated with the impinging water masses give rise to upwelling from 500-3000m to 150-200m. Deacon has commented on the significance of the Weddell Gyre and its associated phytoplankton fecundity with the maintenance of the krill stocks in the region (Knox, 1983, p.23).

Further to the north, a complex interaction of Antarctic Surface Water and Subantarctic Water occurs at the Antarctic Convergence, or Polar Frontal Zone. Perturbations on these frontal boundaries result in the formation of eddies with typical observed diameters in the Drake Passage of 80km. To the south of New Zealand, they may be two to three times larger. Eddies may endure in the surrounding water mass for periods lasting from days up to years. Highly variable in their properties, they are a mechanism for the distribution of heat, salt, nutrients and marine organisms (Knox, 1983, p.24, Efimov and others, 1986).

Between the fronts, three major water masses may be identified, the Antarctic Surface Water, Circumpolar Deep Water, and the Antarctic Bottom Water referred to above (Figure 5). It is the 2km thick southward mixing Circumpolar Deep Water which wells up to replace divergent surface waters, continuously transporting nutrient salts as it does so. This mechanism augments the trophic effects of wind driven currents and
Figure 5: Distribution of water types in the Southern Ocean. (Lutjeharms and others, 1985, p.12).
topography. Observations of nutrient salt concentrations (Knox, 1983, p.26) indicate that levels in Antarctic waters rarely fall below the maxima observed in temperate waters, and are generally in excess of phytoplankton requirements. Salt levels remain above limiting values even during peak periods of phytoplankton abundance.

The Antarctic is the coldest place on the earth. The winter air temperatures over the Southern Ocean, which surrounds and insulates it, reduce from a mean average of $5^\circ$C at $50^\circ$S to $-10^\circ$C at $63^\circ$S. Cold katabatic winds of considerable violence flow off the ice sheet across the Southern Ocean. Speeds of 100-200kts have been observed in coastal regions at the mouths of particular valleys. The effects of these winds can be observed at distances of up to 10 to 15 nm from the coast (Tchernia, 1980, p.55). Further out to sea, predominantly easterly winds near the continent give way to the westerly circumpolar system described above. The Westerlies have the regularity of a trade wind system.

The violence of the wind increases with the latitude, and is accentuated by the continental restriction at the Drake Passage. Average strengths of Beaufort 5-6 (18-24 kts) are exhibited, sufficient to give rise to a fully aroused sea of state 4-5.
TABLE 1: WAVE HEIGHTS IN THE SOUTHERN OCEAN

<table>
<thead>
<tr>
<th>Height</th>
<th>0-3ft</th>
<th>3-4ft</th>
<th>4-7ft</th>
<th>7-12ft</th>
<th>12-20ft</th>
<th>20-20+ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea state</td>
<td>0-3</td>
<td>4</td>
<td>5-6</td>
<td>7</td>
<td>7</td>
<td>8+</td>
</tr>
<tr>
<td>West Wind Drift</td>
<td>10%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>10%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>15%</td>
<td>10%</td>
</tr>
</tbody>
</table>

(Adapted from SP-68 p.61).

The low temperatures, wind velocity, and resulting sea states have a major significance on the fishing vessels which have to operate in these waters, and the surveillance measures, aircraft and surface craft which may be utilised to police their activities.

The region of high pressure at the South Pole is surrounded by a system of lows, typically four or five in number, which originate between 30°S and 40°S, and migrate in a generally easterly direction around and towards the Antarctic continent, penetrating it only in the region between the Ross and Weddell seas. These depressions feature very low pressures, and are advected at an average rate of 12.5 kts. (Deacon, 1984, p.81-84; Tchernia, 1980, p.52-55) (Figure 6). The passage of lows and the interaction of air masses brings extensive cloud cover and precipitation (Figure 7). This can be of considerable volume, although inevitably, higher latitudes bring solid rather than liquid
Figure 6: Tracks of depressions in the Southern Ocean. (Tchernia, 1980, p.55).
Figure 7: Zonally averaged total cloudiness in the Southern hemisphere. (Newton, 1972, p.102).
precipitation. An indication of the precipitation in the region, including the continent, is given below:

**TABLE 2: PRECIPITATION IN THE SOUTHERN OCEAN REGION**

<table>
<thead>
<tr>
<th>LATITUDE</th>
<th>VOLUME</th>
</tr>
</thead>
<tbody>
<tr>
<td>40° - 55°S</td>
<td>1000 mm yr⁻¹</td>
</tr>
<tr>
<td>55° - 65°S</td>
<td>1000-500 mm yr⁻¹</td>
</tr>
<tr>
<td>65° - 70°S</td>
<td>500-200 mm yr⁻¹*</td>
</tr>
<tr>
<td>70° - 90°S</td>
<td>&lt;200 mm yr⁻¹*</td>
</tr>
</tbody>
</table>

* = equivalent of water.

(Tchernia, 1980, p.52).

The presence of ice over much of the Southern Ocean is both highly significant for the Antarctic ecosystem, and a potential hazard to fishermen operating in these waters. Figure 8 gives the approximate mean winter maximum and summer minimum extent of the sea ice, and indicates the maximum observed distribution of icebergs in the Southern Ocean.

The massive ice shelves of Antarctica calve distinct, tabular icebergs of enormous mass which tend to drift with the current unless grounded. They have been observed as far north as 35°S in the South Atlantic (Tchernia, 1980, p.60).

The surface area covered by the sea ice has been calculated at 25.5 * 10⁶ km² towards the end of the austral winter, and extends to surround several of the peri-Antarctic
Figure 8: Distribution of sea ice and icebergs in the Southern Ocean. (Tchernia, 1980, p.62).
islands. The comparative area for late summer is some $13 \times 10^6$ km$^2$ (Knox, 1983, p.24-25). The nature and distribution of the pack ice are highly variable, as is the boundary with the open ocean. The mean thickness of the sea ice surrounding Antarctica is 2m. Sea ice is transported primarily as the result of wind forcing.

Although the Southern Ocean is an important area for shipping, neither the traffic to and from Antarctica, nor between Southern Ocean ports is high in volume by oceanic standards. There is a massive and essential passage of merchant ships around the Cape of Good Hope. In particular, this flow of commodities includes crude oil from the Persian Gulf bound for Europe and the United States. A somewhat more moderate stream of merchant vessels transects the Drake Passage when passing between the Pacific and Atlantic Oceans.
SECTION IV: THE FOOD WEB AND BIOLOGICAL RESOURCES OF THE SOUTHERN OCEAN

As with any ecosystem, the biological resources which are harvested by Man are elements in a food web of considerable complexity. The capacity of that structure to withstand harvesting by Man lies at the heart of living resource management, and is one of the determining factors in the policing strategy.

Many of the relationships within the Antarctic marine environment are improperly understood, and some speculative links between producers and consumers have been incorporated into the ensuing discussion for completeness. A simplified representation of the marine food web is given in Figure 9. Despite its critical importance within the Antarctic ecosystem as a whole, there is no suggestion that the marine environment stands in isolation from the terrestrial environment. Nor can the links between the sub-Antarctic and the temperate biological environments be denied. The diagrammatic representation has been adopted merely as a vehicle to illustrate the many complex factors and consequences attendant upon biological resource harvesting. In practice, marine biologists treat imperfectly understood systems with caution, and calculations of maximum sustainable yield (MSY) for a particular species are conservative.

At an elementary level, the Antarctic marine food web can be regarded as consisting of five principal trophic levels. At the foundation of the system lay the decomposers; the planktonic microfauna, benthic microfauna, meiofauna and macrofauna. Above the decomposers are the primary producers, the phytoplankton, such as Fragilariopsis
Figure 9: The Southern Ocean food web. (Modified from Clarke A, 1985, p.333).
antarctica, which are cropped by the primary consumers in the trophic level above. Crucial amongst these, both to the food web and as a resource in its own right, is the macrozooplankton euphausid *Euphausia superba* (Figure 10).

The krill, in particular the *Euphausia superba*, stand at the centre of the food web. Their distribution is effectively circumpolar (Figure 11) although swarms fluctuate in depth and distribution. Concentrations are often to be found in the vicinity of peri-Antarctic islands, such as upwelling zones in the lee of the landmass, where they support a number of top level predators.

It is thought that krill are not exclusively herbivorous, and that they feed upon nanoplankton and copepods (Clarke A, 1985, p.332). Moreover, they are not the exclusive occupants of their trophic level. Much of the grazing of small phytoplankton can be attributed to other zooplankton, and also protozoans such as tintinnids. Ciliate protozoans and crustaceans in early larval stages are also consumers of bacteria, and clearly, there is a sophisticated pattern of trophic relationships between the primary consumers and their prey. However, in terms of relevance to the animals occupying the trophic levels above, krill are an irreplaceable link above which the competing predators are bound. It is for this reason that harvesting restraint, and hence policing, are both important and area dependent.

An estimate of the total standing stock of krill made as the result of the First International BIOMASS Experiment (FIBEX) was reported at $650 \times 10^6$ t (Laws, 1985, p.2). This figure was derived from the multiplication of averaged values from
Figure 10: Krill: *Euphausia superba dana*. (Everson, 1977, p.34).
Figure 11: Distribution of krill in the Southern Ocean. (Everson, 1976, p.16)
representative sampling areas by the total surface area of the Southern Ocean. Doubts have been expressed as to the validity of this approach and the subsequent result (Everson, personal communication). The difficulty that scientists working in this field may have in expressing confidence in biomass estimates for particular trophic levels is a point well taken. However, the FIBEX estimate makes interesting comparison with the figure of $6400 \times 10^6$ t of phytoplankton noted by Clarke (Clarke A, 1985, p.332), based on the annual carbon production estimated by Holm-Hansen and others. The conversion factor from primary production to primary consumption appears at least plausible.

The level above the krill and other primary consumers is occupied by true fish and cephalopods. Some 200 species of fish have been reported south of the Antarctic Convergence and around the peri-Antarctic islands (Kock, 1985, p.173-174). These animals occupy the deep water and shallow environments and are both pelagic and demersal. Of these, six species are reported as being of commercial significance (Figures 12 and 13):

- mackerel icefish (*Champsocephalus gunnari*)
- Patagonian toothfish (*Dissostichus eleginoides*)
- grey notothenia (*Lepidonotothen (=Notothenia) squamifrons*)
- marbled notothenia (*Notothenia rossii*)
- Gunther’s notothenia (*Patagonotothen guntheri*)
- sub-Antarctic lanternfish (*Electrona carlsbergi*)
Champsocephalus gunnari

Dissostichus eleginoides

Notothenia rossii

Figure 12: Principal antarctic fish species of commercial value (1). (Gon and Heemstra, 1990, p.286, 306, 385).
Figure 13: Principal antarctic fish species of commercial value (2). (Gon and Heemstra, 1990, p.151, 296, 312).
These last two species have been utilised for fish meal, while the others are suitable for direct human consumption (Kock, 1994, p.4).

Of great commercial value also are the shortfin squid (Illex argentinus) and common squid (Loligo gahi) which are found in great quantities on the South American continental shelf (Figure 14). Squid are carnivores whose voracity is exploited in harvesting (see Appendix A). They also form an important part of the diet of many of the cetaceans, seals and birds. An Antarctic cephalopod biomass of over $100 \times 10^6$ t has been suggested by Clarke (Clarke M, 1985, p.199).

There has been a supposition that as a result of the decline in the whale population caused by commercial whaling, a surplus or unutilized volume of krill is available for exploitation in the Southern Ocean. This argument has been refuted by commentators such as Gambell (1985 p.240).

Population studies indicate that whatever krill was made available from the standing stock as the result of the devastation of the baleen whales in the Antarctic has been utilized by other species, principally seals. Consequently, if Man's use of the living resources as food is to be rational both from the necessity to preserve a given fishery, and the intention to preserve the structure and balance of the ecosystem, there will have to be levels set for each species, and unpopular choices made, limiting both the harvesting and population levels for given species. Conservation implies management and the properly planned use of biological resources. Consequently, it also implies an effective policing system, to enforce the management regime.
The common squid *Loligo gahi*

The shortfin squid *Illex argentinus*.

Figure 14: Principal antarctic cephalopods of commercial value. (Falklands Islands Government, 1989, p.7).
The relative structural simplicity of the Southern Ocean food web has given concern regarding its ability to withstand the onslaught of modern catching methods. Southern Ocean fish species have an innate vulnerability which goes beyond the nature of their position in the food web. Their biology is adapted to the polar environment and they tend to exhibit characteristics such as slow growth rate, late sexual maturity, and the production of large yolky eggs which are fewer in number than comparative mid-latitude species (Laws, 1985, p.2).

The Southern Ocean fisheries cannot be viewed in isolation from the Antarctic marine ecosystem. The destruction of a species of mid-level predator such as fish may not be possible by commercial exploitation alone. However, the elimination of some of the top level predators by direct catching and over-utilisation of their food supply may well be.
SECTION V: THE DEVELOPMENT OF LIVING RESOURCE EXPLOITATION IN THE SOUTHERN OCEAN

The history of living resource use in the Southern Ocean has generally followed a pattern in which animals of a particular order or species were exploited until commercial considerations have forced a reassignment of assets to an alternative order or species. Recently, this pattern has altered with the occurrence of two linked phenomena. First, the establishment of international agreements under the aegis of the Antarctic Treaty System, the United Nations Convention on the Law of the Sea (UNCLOS), and associated domestic legislation. Second, a general trend amongst the world population to favour conservation of the environment, and especially, the protection of particular species of top level predator.

Fishing was not the first use of living resources to be undertaken in the Southern Ocean. The late eighteenth century saw the beginning of sealing on the sub-Antarctic islands (Kock, 1994, p.3). The target species were the fur seals *Arctocephalus gazella* and *Arctocephalus tropicalis*. Thereafter, southern right whales (*Eubalaena australis*), elephant seals (*Mirounga leonina*), and some species of penguin were exploited throughout the nineteenth and into the early twentieth century (Kock, 1994, p.3). The catching of rorquals and sperm whales occurred for the first 85 years of this century. Elephant seals were taken, albeit in controlled numbers, at South Georgia and Isles Kerguelen, and intermittent exploratory takes of ice seals are reported between the years 1963 and 1987 (Kock, 1994, p.3).
The origins of commercial fishing in the Southern Ocean are rooted in sealing and whaling activities conducted in the region. Shore-based whaling began at South Georgia in December 1904, at which time, large quantities of *Notothenia rossii* were reported by whalers, *Champsocephalus gunnari* was also present in abundance (Hureau and Slosarczyk, 1990, p.52, Kock, 1992, p.174).

The development of the offshore fishery in the Southern Ocean progressed in three phases. Initial exploratory work in the late 1950s and 1960, a revival of interest in the mid 1970s, and a third period in the 1980s. Despite research and exploratory fishing by a number of nations, including Japan, France, Spain, and the Federal Republic of Germany, it was the fishing fleets of Eastern Bloc countries that predominated, and 85% of the catch was taken by the Soviet Union (Kock, 1984, p.5).

A surge of interest in Antarctic fishing by a number of European nations was motivated by two factors. First, the reduction of North Atlantic fish resources, second, the prospect of restrictions which were likely to arise in fishing activities as the result of changes to the international Law of the Sea (Kock, 1992, p.177). These nations had in some cases enormous capital investment in fishing vessels, and a requirement to secure access to productive grounds.

Despite the research efforts of number of nations, only Poland, Bulgaria and the German Democratic Republic proceeded to commercial fishing in the Southern Ocean. Communist countries operated fishing fleets in the 1970s and 1980s without strict
adherence to economic imperatives. They could also, to a certain degree, call upon the Soviet fishing fleet for facilities such as refuelling. By contrast, nations such as West Germany found distant water fishing expeditions in isolation insufficiently profitable, while krill processing technology was immature for successful marketing (Kock 1992, p.178).

Research and exploratory fishing was undertaken at a wide range of locations in the Southern Ocean, but not always with subsequent commercial operations. The distribution of some of the more significant sites is given at Figures 15 and 16. Figure 17 illustrates the major United Nations Food and Agriculture Organisation (FAO) statistical reporting areas.

In 1978, the Argentines commenced fishing for Illex squid on the Patagonian shelf. The Soviet Union followed Loligo squid harvesting in 1982, and a thriving cephalopod industry has developed around the archipelago and on the associated continental shelf (Willetts, 1988, p.7,10).

In 1981, three French trawlers began commercial operation off Kerguelen. Economic considerations have reduced this to one trawler, the Austral, since then (Hureau and Slosarczyk, 1990, p53). The Soviet Union undertook longlining trials with a single vessel around Kerguelen in the 1990/1991 season. Following this work, a Russian longlining fishery is conducted around Kergulen and the Ob and Lena Banks. No other nation has transformed research into commercial fishing operations in the Indian Ocean sector of the Southern Ocean with the same measure of success (Kock, 1992, p.182). In the same
Figure 15: Fishing grounds of the Atlantic Ocean sector of the Southern Ocean. (Kock, 1992, p.198).
Figure 16: Fishing grounds in the vicinity of the Kerguelen Islands. (Kock, 1992, p.200).
Figure 17: Statistical reporting areas in the Southern Ocean as specified by the United Nations Food and Agriculture Organisation (Everson, 1981, p.91)

Major fishing areas of the Southern Ocean (as specified by the FAO Fishery Information, Data and Statistics Department)

Key:

A. Bouvet Is.
B. Prince Edward and Marion Is.
C. Crozet Is.
D. Kerguelen Is.
E. McDonald and Heard Is.
F. Tasmania
G. Macquarie Is.
H. Campbell Is.
J. Auckland Is.
K. South Is. (New Zealand)

L. Antipodes Is.
M. Bounty Is.
N. South America
P. Falkland Is.
Q. South Shetland Is.
R. South Orkney Is.
S. South Georgia
T. South Sandwich Is.
U. Gough Is.
season, Chile began longlining for Patagonian toothfish around the Scotia Arc, employing up to eight vessels.

In the Pacific Sector of the Southern Ocean, the only finfish industry with promise is with *Dissostichus mawsoni* in the Ross Sea using longlines (Kock, 1992, p.182).

The Southern Ocean resources of the future may well not lie with finfish, but other biota. Knox (1983, p.27) notes the potential of some species of algae. More recently, attention has focused upon cephalopods. *Martialia hyadesi* has been identified by Rodhouse (Rodhouse, 1994), a suggestion which is doubted by others. Crustacea are another possibility, an expedition to the South Georgia area by an American vessel in 1982 yielded some 300t of king crab *Paralomis spinosissima*. However, there may be some difficulty in developing a market for this product. (Parkes, 1994, personal communication).

Fishing operations in the Southern Ocean are impeded by a number of factors, principally the remoteness of the area. Until recently, this was often coupled with the political unacceptability of the few ports in the region. For many of the operators 'acceptable ports' were as much as 1000-1500nm from the fishing grounds. The solution to these problems in some cases has been to organise the harvesting of living resources at fleet level (Kock, 1992, p.204). Details of this style of distant water fishing are given at Appendix A.

Changes in the political availability of ports, as well as the alteration in the legal availability of particular species may already have brought about some alteration in the
pattern of fleet operations. Self-supporting vessels from Poland are reported by Kock as working the South Georgia area for finfish, while the self-supporting French vessel at Kerguelen utilises La Reunion (Kock, 1992, p.206).

Until the advent of recent restrictions the pattern of finfishing repeated that of previous living resource utilisation. Fresh stocks were discovered, harvested to depletion, and fresh stocks were sought. Once the demersal species were successively fished out, benthopelagic stocks (Patagonian toothfish) and pelagic fish (sub-Antarctic lanternfish) commenced in the latter part of the 1980s. Economic considerations brought the end of lanternfish harvesting after the 1991/1992 season (Kock, 1994, p.4).

The difficulty with Southern Ocean fishery management remains the conflict between economics and ecology. Successful commercial fishing is controlled not so much by total catch, as by the rate of catch and the return on capital overheads per unit of time. There is still a great deal of money to be made in the Southern Ocean, and a single day of illegal fishing might bring sufficient returns to cover expedition costs for some vessels. Paradoxically, the need of the fisherman to provide returns as quickly as possible can be used by the enforcing agency to sway the balance of advantages to its favour.
SECTION VI: JURISDICTION AND LEGAL CIRCUMSTANCES IN THE SOUTHERN OCEAN

As with other oceanic environments, the Southern Ocean may be regarded as a system of legal domains with regard to the living resources. Antarctica is subject to a unique form of governance in the form of the Antarctic Treaty System. This alliance has stood the test of time, increasing its membership from the original 12 states (Appendix B and Figure 26). It has evidenced particular regard in the matter of living resources, extending the scope of the legislation beyond the terms and geographical extent of the original Treaty, which applied south of 60°S.

The whole geographical region from the Antarctic continent to the Sub-tropical Convergence is covered by the provisions of the Law of the Sea (LOS). Additionally, a great portion of that area, approximating to the zone south of the Antarctic Convergence, is subject to the CCAMLR agreement. Lying to the south of the Sub-tropical Convergence, and in some cases, within the CCAMLR boundary, there are a number of islands which are subject to the domestic laws of signatory states (Joyner, 1987, p.43) (Figures 18-20).

The vast majority of the Southern Ocean therefore resides within the province of treaty law - both the LOS and CCAMLR. These areas are dignified by public and written codes of conduct. The LOS specifies as a duty the requirement of coastal states both to act in a manner appropriate to the preservation of the living resources in the waters within
Figure 18: Claims and jurisdictions in the Southern Ocean. (Joyner, 1992, p.43).
Figure 19: Falkland Islands Fisheries. (FCO, 1992, p.26).

FALKLAND ISLANDS FISHERIES

Outer limits of the Falkland Islands Interim Conservation and Management Zone (FICZ) declared on 29 October 1986 (Page 6).

Outer limits of the Outer Zone declared on 26 December 1990.
Figure 20: South Georgia and South Sandwich Islands Maritime Zone. (Provided to the author by the Foreign and Commonwealth Office).
which they have exclusive title, and to form regional organisations with states in adjacent sea territories to ensure action in like manner in a larger biogeographical context.

CCAMLR, which grew up contemporaneously with the LOS, may be viewed in the context of a regional organisation whose aim is the preservation of the living resources, albeit an organisation whose goals in preservation transcend future opportunities for rational use. It is unique both in the pioneering nature of the ecosystem approach it takes to resource management, and the Antarctic Treaty System to which it owes its origin.

High seas fishing rights are now codified amongst the other provisions of the LOS. Significantly, CCAMLR numbers amongst its membership all the states with present interests in distant water fisheries in the Southern Ocean and fishing fleets appropriate to the task.

The continental shelves and peri-Antarctic Islands within the Southern Ocean attract EEZs in the cases of Argentina, Australia (Heard, Macquarie, and McDonald Islands), Chile, France (Crozet and Kerguelen Islands), New Zealand (Antipodes, Auckland, Bounty, Campbell, and Chatham Islands), South Africa (Marion and Prince Edward Islands) and the United Kingdom (the Falklands, South Georgia, South Sandwich Islands).

Bouvet Island, which belongs to Norway and has the unenviable reputation of being the most remote point of land on the surface of the planet, has no EEZ (Hydrographer of the Navy, p.101). The available literature suggests that it supports no marine fauna of present commercial significance, and this accords with the meagre nature of its continental shelf. Thus the expense and inconvenience of policing an EEZ would seem
disproportionate. Moreover, it has been suggested that the Norwegian Government considers the establishment of an EEZ as unduly provocative in the context of the international politics of the Antarctic region (Hoel, personal communication).

Nothing in the CCAMLR agreement prevents member nations from enacting domestic legislation of a stricter nature than those measures prescribed under treaty jurisdiction. Similarly, the LOS enjoins signatory states to take measures appropriate to ensuring the protection of the living resources to which they have legal title. However, the major significance of the continental shelves and peri-Antarctic islands in the context of living resource protection lies not in the severity of the legal restrictions devised for their protection, but rather, the facility with which enforcement is possible in the EEZs, in contrast to the high seas regions.

The practice of enforcement both sustains and is sustained by the system of laws and rules which governments are pleased to enact. It is in the nature of human events that law and its enforcement are symbiotic, and both survive and evolve together. In the case of international law, while states may choose from time to time to ignore the provisions of particular treaties in the furtherance of their own interests, there is an increasing tendency in the post-Cold War environment for nations to abide by the precepts of international law, and to seek to justify their actions by reference to its provisions (Whitman, personal communication, 1993).

Despite the moral virtue of this position in contrast to the fervent nationalism of a former and not too far distant age, and the undoubtedly genuine desire to establish the
rule of law as the supreme source of sovereign power in the community of nations, the reality falls short of the aspiration. In practice, any nation which is not party to the CCAMLR agreement has a perfect right to proceed into the Southern Ocean and fish. What is more, its vessels can fish given areas to ecological destruction in the expectation that in the short term, at least, complaints to the flag state will be to little avail.

In contrast, the legal sanctions in an EEZ are largely the prerogative of the coastal state. Harvesting in an EEZ without permission is likely to result in boarding, arrest, fines and other penalties. Failure to cooperate with authorised fisheries officers when challenged can result in peremptory and more catastrophic consequences.

In the Southern Ocean, there have been at least four cases in which failure to abide by or acknowledge the authority of a flag state has led to conflict with regard to living resources. In October 1984, off the French peri-Antarctic islands, the French patrol Albatros sank the fishing vessel Southern Raider. It then arrested the Chuen Yang I for illegal fishing (Headland, 1994a, p.411). In 1986, an Argentine vessel fired upon two Taiwanese squid jiggers in separate incidents when they failed to stop when challenged. The first vessel escaped, but the second suffered a fire as a result of the action. Two men died, and the remaining 21 members of the crew were taken to Argentina pending legal proceedings (Hu, 1987, p.93-118). A third incident occurred in 1991, when the Falklands Island Government demonstrated its determination to police its fishery legislation. The patrol vessel Falklands Desire pursued the Taiwanese vessel Chen Te
for almost three weeks after detecting the vessel harvesting squid within the Falklands' Exclusive Economic Zone. The incident involved recourse to 'hot pursuit' which was called off when the patrol vessel was approaching South Africa (Hull Daily Mail, 20 Jun 91; Hind, personal communication, 1994). More recently, in May 1994 the Argentine frigate Spiro sank the jigger Chin Yuan Hsing following 'hot pursuit' into Falkland Islands waters (Penguin News, 28 May 1994).

CCAMLR invests considerable time and effort in devising measures appropriate to the scientific management of biomarine resources in its area of competence. However, the effectiveness of these measures depends upon adequate policing, and questions have been raised regarding the effectiveness of its system of inspection (Kock, 1994, p.14). Despite this, CCAMLR members have on several occasions taken legal action against their own vessels following complaints regarding contravention of conservation measures. Ultimately, treaty law is based upon voluntary restraint, a problem which has become all too apparent in the case of the International Whaling Commission (IWC). Should a member state no longer wish to be bound by the provisions of either treaty, then mechanisms exist for its withdrawal.

In practical terms, in any fisheries case, limits exist to the effectiveness of appeals to flag states. Very often, issues of economics or politics are at least as significant as those of legal duty. For example, where a flag state is informed that failure to take measures against one of its vessels for fishing illegally will result in the reduction of the allocations of licences to its distant water fishermen, the coastal state will wish to be
assured that it is not adding to the economic injury it has suffered at the hands of the perpetrator. Quite simply, it must be assured that other nations with a more rigorous attitude will wish to take up the licences.

Additional problems may nullify an honest attempt by a flag state to deal with the issue. Where one of its vessels has painted the name of a licensed vessel on its stern, it may have to claim in all candour that identification evidence makes it impossible to prosecute the offender. Moreover, a fishing vessel owner may re-flag his vessel, irrespective of his own nationality, thereby making the task of prosecution practically impossible.

The greatest strength which CCAMLR may bring to bear in the enforcement of conservation legislation is not through the medium of complaints through representatives, but in the domestic legislation which member states enforce in their Antarctic EEZs. Fortuitously, these areas combine the most important fisheries, and important scavenging areas for top level predators.
SECTION VII: DEFINITION OF THE POLICING REQUIREMENT

In order to determine appropriate strategies and means for the policing of biomarine resources in the Southern Ocean, it is necessary first to examine the reasons behind such law enforcement measures. Policing here is defined as the application of measures to ensure obedience to the rule of law, which in this context refers both to domestic legislation enacted by a coastal state and applicable within its territorial waters and exclusive economic zone, and any law or agreed set of regulations it is bound by treaty to honour.

Clearly, there is a great deal of difference between the enforcement of domestic legislation by the coastal state in the case of vessels discovered fishing illegally in an EEZ, and the measures which may be taken by a treaty authority against a member nation whose vessels have violated the terms of that treaty on the high seas. In the former case, when fishing vessels are suspected of illegal fishing, they are usually taken or escorted into a port of the coastal state, where due process of law may be observed. This may in some cases entail the use of force.

In the latter case, where the violation is of treaty law, and the offence has occurred on the high seas, there will be some agreed process of complaint and arbitration, for which due process requires evidence sufficient to ascertain that a violation of treaty terms has occurred. Whilst arbitration may ultimately take the form of legal proceedings at The Hague, the administrative procedures through which disputes may initially be addressed may require evidence of a far less stringent nature.
Policing is the business and responsibility of nation states, acting singly or in cooperation with other nation states. It is undertaken for a number of reasons, including the innate worth of individual laws and statutory instruments, the desirability to uphold the rule of law as an end in itself, and the value of collaborative agreements held in common with other nations. In addition, and of particular relevance to the Antarctic region, resources policing may be an aspect of good governance suitable for the perfection of a claim to a particular territory - a demonstration of the attributes of statehood by the exercise of sovereign powers.

This latter motive has been ascribed by at least one commentator (Hu, 1987, p.93-94) to the actions of the Argentine Government in 1986 when one of its vessels opened fire in two separate incidents concerning individual Taiwanese fishing vessels, the so called 'Squid War'. An alternative view of the more serious of these incidents ascribes to it:

"...the character of bad judgement being exercised in a 'hot pursuit' situation." (Willets, 1988, p.13).

Willets notes that the Argentine account of the events has never been challenged by the British Government, and continues that:

"...It should be remembered that no other similar incidents have been reported before or since and so it cannot be seen as part of a general change to a more aggressive policy..." (Willets, 1988, p.13).

However, the incident may have been catalytic in the establishment of clearly defined fisheries areas around the Falkland Islands.
The enforcement of law is conventionally viewed in two contexts, the punishment of offenders, and perhaps more significantly, the establishment of a deterrent to illegal conduct. However, fisheries protection encompasses a greater range of responsibilities by a state than the protection of its own biological resources. Policing activities need to be sufficient to ensure that its laws are not flouted - not merely to prevent an affront to the rule of law, but also to enact a government's duty to honour treaty agreements. A failure in this latter regard might ultimately cost it more than fish on the world stage. For that reason, even in an age which may appear increasingly ruled by the accountant and fund manager, it would be an unwise government indeed which set its domestic and international standing at the value of its fishing catch. Fishing licence fees may certainly offset the cost of a policing operation, particularly where a vigorous fishing industry exists, but the financing of fisheries protection must be determined at least in part by wider issues.

Law without enforcement is little more than a collection of thoughts on paper. Its expression gains meaning through the exercise of enforcement; indeed, laws are refined and made public to a great extent through their interpretation and test in courts of law. There can be no justifiable ground for full confidence in the worth of a piece of legislation of any moment unless it has withstood the test of exercise by the judiciary. For this reason, there are particular requirements placed upon policing methods and technology, and these are largely of a practical nature.
For there to be enforcement, there must first be detection. In the case of fisheries and marine biological resources law, enforcement generally follows a set pattern:

a. detection of a ship within a juridical boundary
b. determination that the ship is a fishing vessel
c. determination that the ship is engaged in some practice which is an offence against the regulations appropriate to the use of biomarine resources in the area
d. detention and conveyance of the offenders to a location where guilt may be ascertained by due process of law

For steps 'c' and 'd' to be undertaken, it is normally the case that the suspect vessel is boarded by a duly appointed official, generally either a fisheries officer, or a naval officer. In the case of treaty violations, treaty law may make provision for boarding to be undertaken, although the United Nations Convention on the Law of the Sea makes very strictly limited provision for right of visit under Article 110; (Theutenberg, 1984, p.145). Generally, it is the flag state which is responsible for the enforcement of the law against transgressors on the high seas.

Nonetheless, observed violations of treaty agreements may well result in complaint procedures, rather than legal measures, and in consequence, sufficient proof might consist of photographic evidence collected from a passing aircraft or ship. Powers of arrest will almost certainly play no part in the proceedings. In the case of violations of domestic law, the evidence to be collected may well necessitate on-board inspection.
While evidence of whaling contrary to the provisions of treaty law could consist of a properly witnessed photograph of the offending vessel hauling a dead whale up its stern ramp, with the vessel’s name and flag clearly visible, evidence of illegal fishing may well be far more difficult to obtain. Nets may well have to be inspected, and logs checked and impounded. Depending on the particular domestic laws, it may well require an experienced eye to witness in person that fishing gear had just been, or was about to be used, to negate any defence to the effect that the equipment was simply undergoing repair whilst the vessel was exercising innocent passage.

In fact, some coastal states, the UK for example, have made it an offence to have fishing gear unstowed within their Southern Ocean EEZs, and visual inspection or photography without boarding may in theory be sufficient to gain a conviction.

Another aspect of living resource protection which may prove a powerful deterrent to wrongdoing lies within the realm of administrative measures. Powers of this nature have already been invested in fisheries officers of some states. For example, a UK vessel was recently directed into port by the Norwegian authorities on suspicion of having irregularities in its catch estimates (Kilvington, personal communication). The inconvenience and enormous expense of these proceedings may be a powerful incentive to precise adherence to coastal state regulations. At best, the catch will have to be sold locally as the result of it thawing while the process of weighing is completed. A hefty fine for inaccurate estimates may well obliterate the value of the expedition, when in fact maintaining perfect figures may be almost impossible when the crew are working round...
the clock, and a trawler is processing up to 50 tons of fish per day (Kilvington, personal communication).

There are circumstances permissible in law in which surveillance systems might theoretically be sufficient in themselves to secure redress against offenders. Take the case of a photograph which has been taken by an aircraft of a fishing vessel committing an act in contravention of some regulation. The photograph has been printed automatically with the position, date and time. There are sworn statements from the aircrew supporting its authenticity, and the image details the fishing vessel, which is clearly identifiable, and which has trawl warps astern. This evidence may be sufficient under a treaty agreement to embarrass the flag state at a treaty meeting. Moreover, the domestic law of a coastal state may permit its admissibility in a prosecution in a case in which the offence has occurred within an EEZ. However, for an offence of this nature, there may be no agreement with the flag state and the coastal state under which extradition proceedings may be entertained. Moreover, the effort and expense of such an undertaking may be so great that the attempt is self-defeating, since it causes the coastal state more injury than the original offence. Worse still, ineffective policing is as offensive as ineffective law. It is the antithesis of deterrence in that it is an example to encourage wrongdoing.

Certain offences, for example the use of nets of improper size, or the failure properly to maintain records, can only be ascertained by physical inspection. Two further
issues weigh against the choice of a purely surveillance-based policing system, and these have to do with vessel identity.

It has become public knowledge that some vessels have their names repainted to evade licensing regulations (Penguin News, 9 April 1994). Consequently, any system relying purely on photographic or visual evidence, such as video tapes or eye witness accounts, may elicit the response by either an errant skipper or an accused treaty member that the vessel is not theirs. Moreover, where two or more vessels each bearing the same false name are accused of an offence, there may be grounds where an image is the only evidence for recourse to the 'cuthroat's defence', in which two defendants blame each other for a crime and are both acquitted because of the existence of a reasonable doubt regarding the identification evidence.

Despite the difficulties associated with remotely collected evidence or data, and the necessity in the case of suspected infringements in EEZs to have a duly appointed person board the vessel, the requirements 'a' and 'b' noted above, that is, the detection of ships and confirmation that they are fishing vessels, present considerable difficulties given the enormous areas to be policed. This is true even if a coastal state has responsibility for only a single EEZ surrounding a peri-Antarctic island. Indeed, it may give the claimant state pause for thought as to whether to claim an EEZ at all, or merely jurisdiction regarding the terrestrial environment. By not claiming an EEZ, embarrassing infringements cannot occur, while there may be considerable benefit to the public purse.

Assuming that states do wish to enforce the law within their EEZs, and uphold in so
far as they are capable the terms of resource protection treaties on the high seas, the
requirements stated above stand. These entail for coastal states:

a. The detection of all surface vessels passing through EEZs throughout the year,
and in all environmental conditions.

b. Identification of these vessels.

c. Sufficient timeliness of the data to enable interception by a patrol vessel or
aircraft.

d. The ability to have a fisheries officer or duly authorised person board vessels.

e. The ability to take measures to enforce the law, if necessary.

The ability to provide a system which fulfils all of these requirements may be either
technically impossible to achieve or far too expensive. The requirements of individual
states rests ultimately with their own political agenda, and will be their own decision.
Any conclusions presented here will not be prescriptive, but rather, examine available
options and highlight their relative virtues and shortcomings. The second qualification to
the above list of requirements is that the difficulty of the surveillance problem suggests
a strategy in which assets are concentrated in particular areas of a given EEZ to save
time, expense, and wasted effort. Historical knowledge is essential in making decisions
of this nature, but in itself may not always be enough. Thus for example, upwelling
areas in the lee of peri-Antarctic islands are sensible locations in which to concentrate a
far as they are capable the terms of resource protection treaties on the high seas, the requirements stated above stand. These entail for coastal states:

a. The detection of all surface vessels passing through EEZs throughout the year, and in all environmental conditions.

b. Identification of these vessels.

c. Sufficient timeliness of the data to enable interception by a patrol vessel or aircraft.

d. The ability to have a fisheries officer or duly authorised person board vessels.

e. The ability to take measures to enforce the law, if necessary.

The ability to provide a system which fulfils all of these requirements may be either technically impossible to achieve or far too expensive. The requirements of individual states rests ultimately with their own political agenda, and will be their own decision. Any conclusions presented here will not be prescriptive, but rather, examine available options and highlight their relative virtues and shortcomings. The second qualification to the above list of requirements is that the difficulty of the surveillance problem suggests a strategy in which assets are concentrated in particular areas of a given EEZ to save time, expense, and wasted effort. Historical knowledge is essential in making decisions of this nature, but in itself may not always be enough. Thus for example, upwelling areas in the lee of peri-Antarctic islands are sensible locations in which to concentrate a
search effort for krill fishermen and whalers. The use of such techniques may reduce by more than half the effective area to be covered.

It can be argued that in place of expensive surveillance technologies, the most appropriate asset required by a fisheries patrol vessel is an experienced fisherman - literally, an individual with a Master’s qualification and several years’ experience in the fishing industry. The concept of utilising poachers as gamekeepers is not novel, and may not be a complete solution, but history suggests that it is effective. Certainly, establishing a database of areas previously fished for particular species and the catches obtained per unit effort is as valuable to the policing effort as the ecological planning.

Considering the effectiveness of administrative powers, the requirements for a suitable patrol vessel or vehicle to enforce the law may be quite simple. As an exercise in policing, it may well be sufficient to chase a fishing vessel away, or cut and retrieve her gear, to achieve deterrence. Indeed it may be more effective since fishing days lost are precious and expensive, while a trawl net can cost some £20,000 to replace - in effect, a fine without the expense and inconvenience of legal proceedings and the risk of failure on technicalities (Knox, personal communication, 1994). Measures of this nature do not require large warships.

Ultimately, any effective policing system must be a sufficient deterrent to potential transgressors. Fishing is a business of risks, and members of the industry share a profession of potentially great rewards. Where deterrence fails, there will be transgression. The aim of an effective resource protection system is to ensure that there
is sufficient risk of penalty to dissuade infringement. This deterrence may be in the form of exemplary penalties, or the visible presence of an enforcement system.

This latter icon of national sovereignty may perhaps be viewed in itself as a requirement of a policing system.
SECTION VIII: LOGISTIC, TECHNOLOGICAL AND ECONOMIC CONSIDERATIONS

From the foregoing discussion concerning the requirements for a policing system for Southern Ocean biomarine resources, consideration will now turn to rival strategies for achieving these aims, some of which are technical in nature, either vehicles or surveillance technologies, while others are techniques. Clearly, there may well be circumstances in which a combination of strategies are employed, both for reasons of economy and operational effectiveness. Moreover, different solutions may well suit different nations when determining their optimum strategy. This will arise not merely from geographical and economic factors, but also political priorities.

The aim of this examination is not the prescription of most appropriate means for the universal case, since no such case exists. Rather, alternative options will be examined and their relative merits discussed. It will be clear that a requirement exists to have a manual element in policing, or rather, policing in the context of living resource protection cannot be conducted by technology alone, irrespective of the level of sophistication and funding.

The following candidate systems and strategies will be considered:

a. Satellite remote sensing

b. Fixed wing aircraft

c. Rotary wing aircraft

d. Airships and aerostats

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e. Drone aircraft
f. Patrol vessels
g. High speed craft, hydrofoils and hovercraft
h. Ground based radar
i. Sea bed sensors
j. Interception of marine radio traffic
k. Data submitted by fishing vessels
l. On board inspectors and other personnel based approaches

Each strategy or system will be compared using a standardised system. The following criteria will be applied:

a. Detection capability.
b. Search efficiency. Area which may be searched per patrol day (nm\(^2\) dy\(^{-1}\)).
c. System availability.
d. Timeliness of data.
e. Capacity to make inspection.
f. Ability to arrest.
g. Support requirement.
h. Particular shortcomings.

Additional comments will be added to expand the description offered for each candidate approach. Discussion of the rival approaches will be addressed in the
Conclusion. Supplementary material, including the mathematics for search evaluation and sensor performance, and information regarding costs, are provided in the Appendices.

Satellite Remote Sensing.

Satellites are used as platforms for a variety of instruments, and have the capacity to search for ships using active and passive sensors. Their use in the South Atlantic in a military role has already received attention (Dobson and others, 1982, p.101, 102). The particular problems of searching for fishing vessels in the peri-Antarctic marine environment make them obvious candidates. Their altitude endows them with broad swath widths, in the order of 100km. In combination with their speed, this enables them to cover very large areas in short periods of time.

Although all satellite orbits are essentially elliptical, the geometry of the orbit can usually be planned such that the sub-orbital point covers the desired area on the earth’s surface to achieve particular aims. In this case, the area it is desired to cover lies mostly between latitudes 40° to 60°S. Depending on the angle of inclination of the orbit with reference to the equator, the sensor swath traced by the satellite as it proceeds on its track can be made to cover a greater area in latitude. For perfect and continuous coverage of an area, the ideal is the geostationary orbit, in which the satellite’s orbital period perfectly matches a sidereal day (one rotation of the earth with reference to the fixed stars). Such an orbit must lie above the equator, and thus the poles are viewed at a low oblique angle.

Various techniques can be used to improve the coverage. For the best coverage of high latitude regions, the most effective orbital geometry is with an orbital inclination of
almost 90° to the equator. The satellite flies on a track which passes from pole to pole, as the earth rotates below it. Thus, successive swaths precess to the west until the entire planet is mapped (Figure 21).

There are two problems which are in the nature of satellites in polar orbits. First, they are more expensive to launch than equivalent vehicles placed in orbits with lower inclinations, because they are unable to take advantage of the angular velocity of the earth. Second, although their coverage is effectively global, the period in which a given point on the planet will be revisited can be several days, dependant upon the orbital parameters. Moreover, the degree of overlap between adjacent swaths varies with the latitude, being greater nearest the poles.

To ensure that reliable information is obtained, the satellite would have to be equipped with systems which are not susceptible to the cloud which is prevalent in the Southern Ocean and peri-Antarctic environment. Sensors operating in the infra-red band, which can be used at night, and at optical frequencies, both suffer from the inability to penetrate cloud. Radar transmissions, although attenuated, can still make detections in such conditions. However, the detection of a vessel by active radar at the ranges in question - some 800km would be a typical orbital altitude - does not provide identification. A system requiring licensed vessels to report by radio to the fisheries authority does eliminate authorised contacts, but there still remains the problem of investigating those radar returns which are unaccounted for. Moreover, the time of the image, and the time of its reception by the fisheries authority, have between them a
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Figure 21: Sub-orbital track of a representative satellite in polar orbit. (Barrett and Curtis, 1976, p.89).
period in which the data must be transmitted to a suitable ground station, processed and interpreted. This interval results in an area of uncertainty surrounding every unidentified contact, which gradually grows in size. If the radius of the area of uncertainty grows at 10 knots, information which is a day late is effectively useless, while an image received in half that time suggests that 36% of the area might have to be searched. Fishing vessels do not trawl at 10 knots, but they certainly might move to another position within the EEZ at that speed.

An alternative approach would be by the use of transponders fitted to fishing vessels, enabling their position to be monitored on a semi-permanent basis. A system of this kind is under consideration in Europe, while another has found favour in the policing of the Pacific fisheries. The element of particular attraction in the latter case is the relatively low cost in comparison with other forms of surveillance (Bailey and Muelhausen, undated).

Such a system comprises a number of elements. Transponders in the fishing vessels are linked to a navigation system such as Global Positioning System (GPS), and transmit not only a code identifying individual vessels, but also their position and other information such as catch rate. Ground stations receive the data, which is passed via an information network to the fisheries agency, where a computer holds a database of responding tracks. These are continuously updated, and may be selectively interrogated.

The cost of the transponders may be borne by the fishermen who purchase one as a precondition to fishing when buying a licence for particular waters. Track behaviour
established from successive recorded positions enables inferences to be made regarding
the activities of the vessel. Being detected while fishing without a working transponder
in a fishing area constitutes an offence, although the notion of being detected presupposes
the existence of a system for inspection - perhaps an aircraft or surface vessel which
patrols the area of interest.

This is a relatively low cost option, which aims at reducing the frequency and
expense of patrol activity. It favours large areas, but entails an acceptance that
limitations on the catch will be fewer once a fishing vessel is in the area. While this may
suit a fishery in the Pacific, the nature of the food web in the Southern Ocean is radically
different. The relatively short links, coupled with the generally low fecundity, and late
sexual maturity of many species, suggests that uncontrolled modern commercial fishing
techniques might damage fish stocks in a very short period of time.

Nor is a transponder system foolproof. Rather, it accepts a certain rate of theft in
exchange for a moderation in the cost of policing. Clearly, there are ways of defeating
the system. Although a vessel which ceases to transpond is treated as having transmitted
a distress call, and this adds the reassurance of additional safety to the often dangerous
business of fishing, the system cannot detect a vessel which enters an area having never
transmitted a signal. Moreover, it cannot prevent collusion between a licensed trawler
and a collaborating vessel to which part of the catch is transferred. Generally, it is
reported that there has been good cooperation between states operating within the Pacific

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scheme. However, there can always be a problem of fishing vessels which transgress the regulations having been re-registered at a flag state of convenience. Even a cooperative state which is the origin of the vessel and its crew may be powerless to intervene against the transgressor. By contrast, a state which provides flags of convenience is unlikely to respond to appeals to take action against one of its vessels precisely because its income depends in part on not doing so.

Detection capability. This is dependent upon the system chosen and the orbital characteristics. In the case of an active radar and an EEZ surrounding a peri-Antarctic island, it might require two or three successive swaths to cover the area, in which time a vessel which has proceeded on an easterly heading may simply not appear. Dependant upon the pixel size of the imaging system, most large fishing vessels should be detectable. By contrast, all transponding vessels should be revalidated at least once per day.

Search efficiency. In the case of the transponder system, a hypothetical system might provide positions on transponding vessels throughout the entire Southern Ocean, at a frequency of not less than once per day. An active radar satellite in a polar orbit should cover an EEZ in a single day, but in successive swaths.

System availability. At present, the only satellites which might be used for this application are the ERS-1, and JERS-1 (Matra Marconi Space, 1993)(Figure 22).

Timeliness of data. Given the proximity of suitable ground station, or the ability to transmit data via other satellites, the principal delay should reside in image processing.

Capacity to make inspection. No capability.
Figure 22: Top: Data acquisition masks for synthetic aperture radar receiving stations in the Antarctic. The dotted line is the mask for a possible future station at McMurdo Sound. Although not shown here, the station at Hobart covers New Zealand and the Southern Ocean to the Antarctic continent. Two further stations, in South Africa, and on Kerguelen, would extend coverage to much of the Southern Ocean. Bottom: The European Remote Sensing Satellite-1 (ERS-1), one of two synthetic aperture radar equipped satellites flying at time of writing. (Massom, 1991, p.99, 278).
Ability to arrest. No capability.

Support requirement. For the application under consideration here, it is assumed that a satellite or satellites launched and operated by particular organisations might be made available to government or international agencies, albeit at some cost. The product is a set of images which are bought and processed by the interested parties, or purchased in a pre-processed format. Data storage limitations in satellites dictate that imaging can only occur within line of sight of a suitable ground station. The procurement of such a station, together with image processing facilities and suitably trained staff would be necessary unless the area to be policed was covered by the reception mask of an existing station with suitable equipment. In the latter case, the recipient fishing authority might pay fees for image reception, processing and retransmission, but would require only a means of receiving and possibly displaying the images. For fully processed data, this might be nothing more than a list of positions on a facsimile print.

Particular shortcomings. The transponder system sacrifices thoroughness for economy, accepting a potentially higher percentage of transgression than might be acceptable to the Southern Ocean marine ecosystem. The principal difficulty in the radar system would probably reside in the period between images.
Fixed wing aircraft

In the maritime environment, the security of twin engines is a basic requirement for such platforms. The aircraft need not be pressurised, and can be of modest size, although it becomes difficult to conduct long missions effectively if crew comfort is wholly neglected.

Large patrol aircraft are primarily designed and equipped for anti-submarine warfare. Although they are more than capable of undertaking the task, they are very expensive. Equivalent endurance may be had with marginally less crew comfort in a smaller aircraft. The endurance of smaller aircraft has been doubled by the addition of underwing fuel tanks, and although radar performance may be much more modest, and a fraction of the cost, flight at a relatively low constant altitude and power conserves fuel and permits visual identification of fishing vessels without the need for constant height changes (English, 1986, p.289). Aircrew training is important if good results are to be achieved even if the aircrew chosen are experienced multi-engine merchant aircrew. Research indicates a minimum some 30 hours per crew (Crutchlow, 1983, p.51).

Larger aircraft may well need concrete or similarly prepared runways of considerable length. This is not exclusively the case, aircraft such as the Lockheed C 130 can operate from relatively poor surfaces, but lighter aircraft may well be able to operate from short, poorly prepared or unprepared surfaces, which increases their utility in operations from peri-Antarctic islands.
Seaplanes have been used successfully in the polar regions (Bertrand, 1971, p.487). The attraction of the seaplane is that it does not require an airstrip. However, there will certainly be limits to the sea conditions in which it can take off and land. These may be overcome to a certain extent if operating from a peri-Antarctic island with an embayment, but the notion of landing next to fishing vessels, launching a dinghy and making inspections is impractical given the statistical distribution of sea states described in Section III.

A novel aviation technology which has come to light in recent years is the development of wing in ground-effect aircraft. Effectively, these are seaplanes which are supported in forward motion on the relatively dense layer of air near to the sea surface, a technique which reduces fuel consumption. A range of vehicles has been designed of which the smallest with an appropriate range (500nm) can operate in Beaufort wind force 4 (sea state 3 in a fully arisen sea). The example of this type of machine most familiar to the West at present, the Ekranoplan A.90.150, can land in sea state 4, and take off in sea state 4-5 (Jane's Defence Weekly, 28 September 1991, p.550, Jane's Intelligence Review, December 1991, p.554-558, Jane's High Speed Marine Craft, 1993/1994, p.313-314).

Detection capability. 50nm has been quoted for a patrol aircraft sortie that requires a search without individual contact investigation (Crutchlow, 1983, p.51).

Search efficiency. 150,000 nm² dy⁻¹. This represents a single sortie within an area of 300nm x 500 nm. In a sortie with a track length of some 1500nm, lasting 6 to 7
hours, 90 contacts might be investigated and photographed (5 minutes per vessel). An area might be limited to 70nm x 70nm (4900nm²), depending on the spacing of the vessels. Electro optical aids can enhance search efficiently by reducing the track distances required to close and investigate contacts (Crutchlow, 1983, p.51).

**System availability.** Suitable aircraft are available for purchase.

**Timeliness of data.** Once airborne, those violations which are detectable by visual inspection, such as being a vessel with no licence, or having gear unstowed, may be reported immediately.

**Capacity to make inspection.** No capability.

**Ability to arrest.** Duly authorised aircrew overflying a fishing vessel may arrest that craft, and should it attempt to escape, pursue it from the area of national jurisdiction under circumstances of 'hot pursuit'. Due to limitations in the endurance of aircraft, it may be necessary under such circumstances for the aircrew to summon the assistance of a patrol craft to complete the arrest. In the UK, circumstances have occurred in which fishing vessels apprehended by aircraft have proceeded to port. In those cases, the masters of the fishing vessels pleaded guilty to the charges, and the validity of the authority to arrest was therefore not reinforced by precedent (Crutchlow, 1983). Nonetheless, for the generic case in the legal environment of an EEZ in the Southern Ocean, this would be a matter for domestic legislation.

**Support requirement.** Technical support facilities will be required. In the case of a light aircraft, this might be no more than a single individual with appropriate certificates.
Open air maintenance is possible, but not appropriate to normal civilian flying circumstances, and some form of shelter is therefore necessary. Small aircraft can operate from relatively poorly prepared surfaces.

**Particular shortcomings.** Aircraft, especially seaplanes, are weather limited to a greater extent than surface ships. The Ekranoplan wing in ground-effect craft has quite high sea state limitations, but is reported to have failed to meet its fuel efficiency standards. There have also been problems with corrosion (*Jane's Intelligence Review*, December 1991, p.554).

**Rotary wing aircraft.**

Helicopters have been used in fisheries protection as intervention, as well as surveillance craft (Hind, 1994, personal communication). The minimum standard of machine required would have twin engines, winch and radar. Amphibious helicopters such as the Sea King have boat hulls and can land on water, but in limited conditions, and it is not a routine circumstance.

**Detection capability.** 47nm assuming an aircraft at 457m.

**Search efficiency.** 12540nm$^2$ hr$^{-1}$.

**System availability.** Aircraft are available for purchase.

**Timeliness of data.** Instantaneous, once the aircraft is in contact.

**Capacity to make inspection.** It is possible to winch a fisheries officer down to make an inspection, or launch a dinghy in a limited sea state. Ultimately it is a matter of
individual judgement as to whether it is safe to winch or not. In air sea rescue terms, it is considered that if conditions are permissive of helicopter operation (windspeeds of 50-60kts), it is possible to winch (Kirkup, 1994, personal communication). Similar risks are not acceptable in routine resource policing.

Ability to arrest. A rotary wing aircraft is as capable of making an arrest and engaging in 'hot pursuit' as a fixed wing aircraft.

Support requirement. There will inevitably be a higher maintenance burden for a twin turbine engine helicopter than a small twin piston engine light aircraft. Although the vertical takeoff and landing capability of the machine reduces the requirement for prepared surfaces, covered servicing facilities will be necessary.

Particular shortcomings. The compensating reduction for the helicopter's flexibility is its cost and maintenance burden in comparison with some fixed wing aircraft.

Airships and aerostats

Balloons have been used extensively in maritime surveillance for a number of applications. They have also been used both with spectacular success and tragic failure in the Arctic, by pioneers such as Umberto Nobile who reached the North Pole in the Norge airship in 1926 (Imbert, 1992, p.74, 75). More recently, tethered balloons equipped with radar have been employed by the United States Government in the Gulf of Mexico as a means of detecting low altitude aircraft used by drug smugglers.

The principal advantage of balloons over other aircraft is endurance. Although there is a limit to the time that a radar on a tethered balloon can be operated without routine
maintenance, the number of operational hours flown is far greater than an equivalent number of heavier than air platforms. However, there have been a series of losses to autostats in United States Government service, primarily the result of high winds (System Planning Corporation, 1992, p.18).

Airships have an endurance which is rather more limited than that of aerostats, due to limited fuel supply and crew fatigue. However, they compare very favourably with large multi-engine patrol aircraft in term of cost. Their comparative shortcoming resides in their slow speed - 50kts would be a typical figure for cruising speed, with 27kts an average for economical cruising speed. Thus, although cheaper to purchase and support, they can cover a rather more limited area with their sensors, and are more likely to be weather limited by adverse wind conditions.

An additional problem is created in ground handling. Airships are vulnerable to gusting wind conditions, and a large ground handling staff may be necessary to cope with difficult conditions. Tethered aerostats are similarly disadvantaged during launch and recovery. Once again, it is the Southern Ocean environment which is the limiting factor.

The best venue for the deployment of aerostats might be from ships, providing a patrol vessel with a balloon lofeted radar to enhance its own search capability, while retaining the capability to board and examine fishing vessels. Considering the case of a patrol vessel searching with a mast mounted radar 20m above sea level, and a radar on a tethered balloon at 305m (1000ft), the area searched per unit of time increases by almost 300% at equivalent speeds. Aerostats have been deployed in this way, both during
wartime for anti-submarine duties, and more recently in the Gulf of Mexico. However, the difficulty of ensuring the balloon’s security during high winds, or if there is strong gusting, remains operationally limiting and probably an intolerable economic risk. The assumption that a modest towing speed might minimise the probability of accident is not necessarily correct, although halving the search speed in the scenario cited above still offers an advantage of 95% in the area covered per unit of search time. The enormous volume of the gas envelope dictated by the relative buoyancy of helium necessitates an aerostat which might easily be a third of the size of an average stern trawler.

Detection capability. Given the slow speed of the vehicle, the best maximisation of an airship’s capability might be to climb to the machine’s pressure altitude, or an operational altitude of 2896m, which is below the limiting altitude for an unpressurised aircraft, and compile a picture of surface traffic. Having eliminated licenced vessels, and contacts known to be other than fishing vessels, a plan could then be devised to proceed directly to particular contacts of interest having consideration for wind conditions and endurance.

Search efficiency. Under conditions in which the wind was steady but gave an airship practically no speed advantage, the method suggested above would provide a line of sight range of 119nm. This gives an area in which a picture of traffic could be compiled of 44,488nm², over a third of the area of an EEZ. In still air, and assuming a patrol altitude of 457m, a line of sight range of 47nm, would suggest a swept area of 4,750nm hr⁻¹.
System availability. Both aerostats and airships are available at the present.

Timeliness of data. Instantaneous once in contact.

Capacity to make inspection. An aircraft such as an airship, which has the capacity to hover, could winch a fisheries officer to the deck of a fishing vessel to make an inspection. Another approach which has been examined has been to board a vessel from an inflatable powered boat which has been lowered into the water from the airship. In the case of the aerostat, the system is for surveillance only.

Ability to arrest. Direct intervention from an airship is possible, but in general would require the compliance of the fishing vessel. If a vessel ignored an order to proceed to a port, there are effectively three courses of action open to the airship. It could attempt to put arresting officers on board by winching them down or having them abseil to the deck, but this is generally a task for trained young personnel such as a police firearms unit or marines. Random course alterations and difficult wind conditions would rapidly increase the risks to the arresting officers. The second possibility would be utilise the superior speed of the airship to lay a line of man-made fibre such as braided nylon to tangle the fishing vessel’s screw. In the last resort, firearms might be used from the airship gondola.

Support requirement. An aerostat deployed from a patrol vessel would require a winch and either a tethering tower or some form of deck support on the stern of the vessel. One of the vessel’s own winches might suffice, and the crew might be trained in handling the balloon. In addition, they might operate the radar, although a radar
maintenance specialist might be needed. A specialist advisor in balloon handling and operational limitations would be needed at least initially to minimise the risk to the aerostat. Routine maintenance is necessary for both aerostats and airships, and this suggests the procurement of two envelopes for an aerostat installation. Due to difficulties in ground handling, large numbers of staff are often needed - perhaps 14 when wind conditions are unfavourable. A hangar or mooring tower would be needed for an airship. Mobile mooring towers are in use. Aerostat operations might be conducted from a winching vehicle such as a truck, with further vehicles for bottled gas and the radar monitor.

**Particular shortcomings.** Considering the wind conditions in the peri-Antarctic islands, this innate vulnerability of lighter than air aircraft must weigh against the employment of these vehicles. The static nature of aerostats, limits their surveillance capability. To obtain line of sight to 200nm, an aerostat would have to be flown at 8190m (26,863ft). Although these altitudes are technically possible, the weight of the radar and the tether cable suggest an envelope of unwieldy dimensions for winching and ground handling. The generally slow speed of the airship inhibits its search capability and the number of days it is able to fly due to high winds.

**Drone aircraft**

Drones are not yet an intrinsically cheap form of aviation, and therefore not yet a cheap means of surveillance. However, development work continues on this technology.
An Australian project, the Aerosonde, aims to provide a light sensor platform with long endurance, utilising Global Positioning System (GPS) receivers to determine the attitude of the airframe, and solar energy to provide propulsion power (Bailey and Muelhausen, undated, p.20).

At present, drone technology is not 'proven' in this particular application. In fisheries management, aircraft loss rates typical of battlefield reconnaissance systems are unacceptable. One of the problems with unmanned aircraft is that of recovery, which in part accounts for the loss rates. There are three methods in common use, runway, netting and parachute. In the latter, shock reduction measures such as the deployment of air bags aim at the protection of the airframe and its sensor package. Although many peri-Antarctic islands have either a runway or suitable flat operating area, one of the attractions of the drone is in those environments where these are not available, for example in the case when it is desired to operate the system from fisheries patrol craft, it is still possible to launch and recover the aircraft.

Another problem is associated with the balance between sensor capability, sensor cost, and remote control. Drones have a demonstrated capability with cameras and infra-red linescanning sensors. The use of SLAR is not technically impossible, but the additional weight and expense of radar equipment would necessitate a larger and more reliable machine, which would in turn increase the cost. Due to the sensor limitations, the cloud base limits the operational altitude of the drone, and although pre-programmed flight has been demonstrated, the remote control regime is effectively limited to direct
line of sight. With reduced effective operational altitude, this would be diminished, as would the dimensions of the swath covered by the sensors.

The utilisation of an unmanned aircraft which is remotely piloted via a data link, rather than pre-programmed, has advantages in fisheries surveillance. The information from the on board television camera is more timely, and can be preserved on tape in case the machine fails to return, or the sensors are damaged on recovery. Indeed, it is not too far fetched to imagine a situation in which the drone operator detects an offence being committed, alerts the fisheries officer, who then contacts the vessel, and informs the master that he is to proceed directly to port to face questions regarding his activities. The tapes would become evidence. Failure to comply would result in response by a patrol vessel, guided by the fisheries officer, who could provide continuous position information on the fishing vessel as long as the drone was able to maintain contact.

Detection capability. With still photography, a fan of cameras or sequential imaging could provide information from horizon to horizon along the axis of flight. Detection is therefore limited by the aircraft altitude, focal length of the cameras, weather, and mission duration. Increased focal length would add to the definition at the expense of field of vision, and in consequence the rate of film consumption per distance covered. The use of a video camera or other raster scanning imaging device might limit detection range to less than comparable naked eye visual limits unless some form of lens control with automatic or commanded zoom and panning was available.
Search efficiency. A typical system, operating at 3000m, can scan a swath of 400m * 200m for 4.5 hours at a maximum speed of 147km hr⁻¹. 11,760km² hr⁻¹ (3429nm² hr⁻¹). This would give an area coverage of 52,920km² (15,429nm²). However, that would be at a maximum range of 100km (62nm) from the control vehicle (Kennedy and others, 1983, p.132-133).

System availability. There is no system available for direct purchase at present.

Timeliness of data. Instantaneous, if a video link is used. With a data recording package, timeliness of the information would be a function of the duration of the mission, data processing time and time spent in evaluation.

Capacity to make inspection. No capability.

Ability to arrest. Limited to the technique described above.

Support requirement. Drones are usually deployed from a support vehicle, perhaps with a launch rail, recovery systems and remote control system or homing beacon.

Particular shortcomings. At time of writing, there is no system which can be purchased for marine resource surveillance and utilised without modification. Consequently, there would be development costs involved in such a venture. Drones are limited to line of sight in remote control, and likely to be expensive if required to operate reliably for extended periods of time on autopilot in the environmental conditions of the Southern Ocean. Attrition through use and during recovery would increase the cost.
Patrol vessels

The patrol vessel is the classic means of undertaking marine resource protection. Although not necessarily elaborate, it must at least be seaworthy and sea kindly. The size of a vessel is not necessarily a guarantee of safety, but to achieve speed, displacement or planing vessels are governed by a set of mathematical criteria. Paramount amongst these is length (Brown and Marshall, 1978, p.49-50). To have a speed advantage in a high sea state therefore, as well as the necessary propulsion power, a vessel must have a minimum length. If fishing vessels are capable of transit at 15kts, the patrol vessel requires a speed advantage. 24kts can be achieved in conventional vessels, exploiting the geometry of the resistance curve without recourse to a lightweight structure which may leave a vessel vulnerable to the punishing conditions of patrol work, and more powerful propulsion machinery which adds to the cost. Vessels rarely achieve trials performance on duty. A ship which has achieved 24kts at build will probably run at 20.5kts in practice, and thereafter lose 1kt per year to fouling until the hull is cleaned. Thus, after 2 years’ service, a vessel designed for 24kts, when detecting an offender, will be in a tail chase from approximately 10nm, the distance at which she is likely to be spotted, with a 3.5kt advantage. It will take her some 3 hours to overhaul the fishing vessel, and she will do so after a sea chase of some 56nm. To achieve 20kts in sea state 5 the patrol vessel will need to be 80m in length (Brown and Marshall, 1978, p.50).

Not all offenders are likely to be caught by a patrol vessel, but to provide an advantage over unwilling detainees, a minimum size and power of vessel are necessary.
It is necessary also if crew capability is to be preserved. Although influenced by physiological and psychological circumstances, sea sickness is brought on by vertical acceleration in the 0.15Hz-0.5Hz band at a threshold of some 0.1g. Vulnerability to seasickness varies with individuals, but even those who do not actually vomit will have their abilities impaired in tasks such as chart work (Brown and Marshall, 1978, p.50). Once affected, the condition persists despite a reduction in vertical acceleration. Again, hull design and minimum size are important in reducing this debilitating condition.

Other design features, to prevent slamming, and to minimise the amount of water brought inboard in heavy seas, also require careful consideration, as does manoeuvrability.

There is no intrinsic merit in sophistication in a patrol craft, indeed, simplicity can be a virtue, as unnecessary complexity can mean wasted investment in material and the personnel who run and maintain it.

**Detection capability.** 10nm assuming a vessel with a 20m mast.

**Search efficiency.** At a speed of 12kts, this would give a search area of 240nm² hr⁻¹.

**System availability.** Suitable vessels can be built, hired, or purchased at present.

**Timeliness of data.** Instantaneous.

**Capacity to make inspection.** Able to inspect unless prevented by weather conditions or fishing vessel behaviour.

**Ability to arrest.** Able to arrest.
Support requirement. May operate for extended periods at some distance. Depending upon the vessel, refuelling and victualling will require the use of a dock or anchorage.

Particular shortcomings. A relatively slow platform in a stern chase.

High speed craft, hydrofoils and hovercraft

High speed craft have received serious consideration as patrol vessels in the fishery protection role. Their great attraction is the ability to combine surveillance with enforcement. Turbine propulsion adds to the cost of a vessel, although diesel powered hovercraft of ship construction, rather than aircraft construction, are available.

The speed of these craft greatly adds to their deterrent effect in policing, as their sudden appearance, and the inability to outrun them in a chase, negates evasion and the concealment of evidence. The speed performance of hovercraft deteriorates rapidly with increasing wave height. Hydrofoils can be very steady vessels when foilborne, and even when stopped the foils may damp vertical acceleration. Nonetheless, pauses in a mission for periods of approximately an hour while inspections are made are likely to be uncomfortable for the crew.

Hovercraft have been inverted by high seas, although model tests for a large hovercraft, the SRN.4, indicate that it could not be inverted or overwhelmed, even when rafted. Hydrofoils become monohulls in high seas states, although a potential exists for severe damage if a foil hits a floating mass such as a growler or bergy bit.
Detection capability. For a foilborne hydrofoil with a radar at approximately 11m above the mean water line, the detection range will be approximately 7.3nm. For a hovercraft with a mast height of 9m, when under weigh, 6.6nm.

Search efficiency. $628 \text{nm}^2 \text{hr}^{-1}$ for a foilborne hydrofoil at cruising speed. $660 \text{nm}^2 \text{hr}^{-1}$ for a hovercraft at cruising speed.

System availability. Both hydrofoils and hovercraft are available for purchase.

Timeliness of data. Instantaneous once in contact.

Capacity to make inspection. Fisheries officers may be landed from hydrofoils using rigid boats. It may be possible to board from a hovercraft direct, as the deflated skirt acts as a fender.

Ability to arrest. Both types of craft can be used to arrest. Although their endurance is limited, they might transfer a boarding party and proceed independently. Both types of craft have been armed, although weight constraints, particularly in the case of the hydrofoil, militate against the carriage of heavy systems.

Support requirement. A hydrofoil is essentially a fast reaction platform requiring a pier or sheltered anchorage. A hovercraft, although for preference requiring a maintenance building, could utilise a beach of modest gradient to come ashore.

Particular shortcomings. Both hydrofoils and hovercraft are limited by weather, becoming hullborne and rafted respectively. A diesel powered hovercraft manufactured in the UK has a Civil Aviation Authority limitation of 2.5m maximum wave height, with a significant wave height limit of 1.8m. Survival limits may be twice those figures.
100t hydrofoil can retain a speed of some 40kts up to sea state 6, becoming hullborne thereafter and rapidly reaching its design limit. Endurance is also limited, both by fuel and crew tolerance.

**Ground based radar**

Coastal radar has been used for many years for the monitoring of marine traffic, particularly in harbours and congested seaways. A common practice is to use systems within in the I/J bands - some 8-12GHz. Systems at these frequencies should have sufficient range to detect ships to the line of sight horizon (calculations for generic systems may be found in Appendix D). Meteorological phenomena can degrade the performance of such systems. Water vapour in the air can absorb radar signals, while rain, and to some extent hail, can attenuate and scatter the energy, since each droplet acts in effect as a reflector. Ice crystals and snow result in little attenuation, even at high rates of fall, (Rohan, 1983, p.209, 211). Radars are designed to overcome the attenuation of fog.

While an improvement in the line of sight can be achieved by simply increasing the height of the radar antenna, a number of considerations must be addressed in the choice of a radar location. Slopes may be used to increase target returns by phase addition, while ground clutter and nulls must be minimised (Rohan, 1983, p.196-205). The sea itself produces clutter, although its effects are difficult to predict mathematically. A rough sea can modulate rain clutter, because of amplitude and phase variations in forward
scattered energy (Rohan, 1983, p.211). Some processing can limit clutter effects, for example, the use of circular polarisation. However, there are practical limits to the value of such aids. In the case of circular polarisation, the reduced clutter is accompanied by a reduction in the target return (Rohan, 1983, p.268).

An increase in sensor height in order to improve line of sight may also result in the increased exposure of the sensor to meteorological effects. In the peri-Antarctic islands, the wind can be so severe that anemometers have been destroyed (Headland, 1994, personal communication). The usual solution is to protect a radar with an antenna of any size with a radome, which adds to the cost of site preparation.

An alternative approach to the problem is to employ systems working in the High Frequency band, utilising ground wave propagation. In some cases, information is transmitted in ducts using equipment devised for the purpose. These ducts may be found at the sea surface in the equatorial and temperate latitudes. They are subject to some variability, and cannot be relied upon as a medium for surveillance in polar regions. At least one alternative system is available however, broadcasting in the 4-10MHz band. This equipment utilises the sea as a conductor, sensing the Doppler of target returns. The antenna consists of a row of simple dipoles, which reduces its susceptibility to wind damage. A range of 200nm has been demonstrated, utilising coherent processing to sense target speeds to 0.1kts. The array has a coverage in azimuth of 120°, indicating that a three array system might provide complete coverage for an island, however, the cost of a single unit might militate against this approach.
Contact identification remains a problem, although it may be relieved by the use of transponders.

Detection capability. In the case of I/J bands, the range is effectively line of sight. With the HF system described above, the range is dependant upon sea state, which reduces from 200nm for a large ship target in sea state 3. An increment to sea state 4 results in a 30% reduction in range (Perry, personal communication, 1994).

Search efficiency. Considering the average frequency of observed sea states, an HF radar could monitor 100% of the major vessels in an EEZ for 10% of the time.

System availability. Equipments are available for purchase.

Timeliness of data. Instantaneous within the surveyed sector.

Capacity to make inspection. No capability.

Ability to arrest. No capability.

Support requirement. A building is required for the equipment and its associated diesel generator. Information might be transmitted from a remote station via satellite, microwave links or underwater cables. Apart from maintenance personnel, including attendants for the diesel, operators will be required, although in some cases these might be the fisheries officers if the data is transmitted to the fisheries authority. All radars require routine servicing to ensure performance standards are being met. The maintenance for the HF system is described as 'peripatetic' (Perry, 1994, personal communication).
Particular shortcomings. Higher band systems are vulnerable to damage, and may require expensive radomes. They are also limited in the area they can monitor. The HF system is limited by sea state.

Sea bed sensors

Motorised fishing vessels all emit noise, depending upon the use of machinery. A working ship such as a fishing vessel need not necessarily be underway in order to produce noise, as it still requires to generate power, and run machinery in order to catch and process fish. Depending upon circumstances, this noise can be detected at considerable distances, by underwater passive listening devices, or sonar (SOund Navigation And Ranging). An enormous amount of effort has been invested in the development of these devices for the detection of submarines. This technology is now becoming available for the surveillance of economic exclusion zones, and ranges of 200km are claimed against a typical fishing vessel (Atoll, undated).

Two systems for which information may be obtained from the open literature have been considered. One consists essentially of three hydrophones; the other, rather more elaborate, has a series of hydrophone arrays built up from units of 64 hydrophones. Each system passes its information to a shore station by a cable. Although the three hydrophone system could almost certainly be extended in modules to cover a considerable area, the larger and doubtless more expensive system of arrays would discriminate more effectively against background noise, thus giving greater range against a noise
source of the same sound intensity. Either system could provide range as well as bearing information by triangulation, given an arrangement of sensors such that the triangulation baseline was of sufficient length, and preferably with sensors in simultaneous, or near simultaneous, contact.

Detection capability. The detection capability of the more sophisticated system is examined on the basis of manufacturers’ information in Appendix F.

Search efficiency. In the case of an EEZ surrounding a specimen peri-Antarctic island of 12km radius and circular area, and with a system configuration of arrays at the manufacturers’ prescribed spacing and distance from the shore (100km) continuous cover of not less than 87.3% of the EEZ would be provided (305365km²) (Figure 23). Coverage of the periphery of the area would be dependant upon radiated noise level from particular fishing vessels, and environmental conditions.

System availability. Systems are currently available for purchase.

Timeliness of data. Instantaneous within the surveyed area.

Capacity to make inspection. No capability.

Ability to arrest. No capability.

Support requirement. As with shore based radar, these systems require a shore terminal and staff operating on a shift basis if continuous surveillance is required. The operator requirements probably exceed those of radar; a maintenance engineer is also required. The shore equipment essentially consists of power supplies, a computer system and visual display units. Information might be data linked from remote sites.

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Figure 23: Design based on manufacturers’ information for a sea bed acoustic monitoring system for marine resource protection at a peri-Antarctic island. (Atoll, undated).

A = peri-Antarctic island
B = hydrophone array
C = cable
Particular shortcomings. Underwater detection equipment is even more subject than is radar to the effects of the environment. Careful site survey and system design would be necessary to ensure that local circumstances, such as the presence of ocean fronts, did not unduly inhibit effective performance. By their nature, underwater cables are vulnerable to damage by a variety of means, and this is of particular concern in the peri-Antarctic environment. Although bottom trawling is restricted both by regulation and the local conditions (Kock, 1992, p.198) it may still be undertaken, to the detriment of the system. Moreover, natural phenomena such as the slippage of sediment and iceberg ploughing may damage cabling; many of the peri-Antarctic islands are volcanic in origin, and some are glacierized.

Interception of marine radio traffic

This system of surveillance might operate in two ways. First, signals intercepted from vessels at sea might provide a position by triangulation. This requires not less than two stations at sufficient distance to provide a reasonable baseline, with both in contact with the vessel making the transmissions. Unlicensed vessels could be removed from a plot of transmitting vessels, and further investigation undertaken of unaccounted for ships. Second, the content of the transmissions themselves might give information sufficient to determine that illegal activity was taking place.

Perhaps the simplest application of this technique is to provide a patrol vessel with a suite of radio equipment, and an antenna for direction finding. Such a system would
enable the vessel at least to obtain bearing information, and act upon it. There will however always be the problem of language to be overcome.

**Detection capability.** Line of sight for VHF and UHF transmissions. HF groundwave will be detectable at ranges of 10-100nm. HF skywave will be detectable, dependant upon environmental conditions, at ranges of 100-250nm with one reflection, and 100-1200nm for more than one reflection. Satellite transmissions are difficult to intercept due to the polarity of the antenna used (Fitts, 1980, p.184).

**Search efficiency.** Not a systematic search system.

**System availability.** Suitable equipments are available for purchase, and many vessels are fitted with VHF band automatic direction finding as standard equipment.

**Timeliness of data.** Instantaneous, subject to the shortcomings listed below.

**Capacity to make inspection.** This is a surveillance system, although it may be associated with an enforcement platform.

**Ability to arrest.** None, but may be associated with an enforcement vessel.

**Support requirement.** Dependent upon the system used, this might be no more than routine maintenance by a technician already employed by the fisheries authority, or indeed servicing when failure occurs.

**Particular shortcomings.** The technique relies upon the illegal vessel making transmissions at a frequency the receiving unit can detect, at a time when the intercepting equipment is tuned to the appropriate frequency range and when atmospheric conditions are permissive. Fishermen might well be aware that their broadcasts are likely to be
listened to, and simply refrain from broadcasting. Moreover, modern vessels may well be equipped with commercially purchased encryption systems. Satellite systems are in widespread use, further limiting detection opportunities.

**Data submitted by fishing vessels**

Fishing vessels are themselves able to participate in fisheries policing, by reporting information on vessels which they encounter at sea. Such a system is of particular value when a number of fishing vessels is operating in a particular area. Where there are rather fewer participants - and in the Southern Ocean EEZs there can be as little as one distant water vessel operating in one area at any one time - collaborative reporting is likely to be of less use.

Where vessels are engaged in similar fishing activities, the paucity of numbers may to a certain degree be compensated for by the fact that longlining or trawling for particular target species tends to take place in particular areas. The best locations for longlining are not necessarily the best locations for creeling; unless both methods and target species are the same, two vessels may not need to be in the same portion of the EEZ. Moreover, where fishing for particular species or by certain methods has been suspended by the management authority, the legal fisherman may have even less chance to be operating in the same waters as another vessel operating illegally.

It is always advantageous to encourage a good relationship between the fisheries authority and licensees. A licenced fisherman may report the presence of another who has
not paid a licence fee, and has therefore taken an unfair advantage of him, but the possibility of collusion cannot be ruled out, particularly if both vessels are owned by the same company. Moreover in distant water fishing, the vessels operating may well be from nations other than the coastal state, thus domestic loyalty cannot be counted upon.

**Detection capability.** The visual identification of a vessel detected in daylight might be accomplished in good conditions out to the visual horizon. If the bridge were some 12m above sea level, this would be some 7.7nm.

**Search efficiency.** This is a random system, dependent upon the behaviour of the reporting vessel, whose highest priority is not detecting illegal fishing vessels. If the vessel is trawling continuously, it might cover some 77nm$^2$ hr$^{-1}$ (1848nm$^2$) per day.

**System availability.** Effectively random.

**Timeliness of data.** Effectively random.

**Capacity to make inspection.** No capability.

**Ability to arrest.** No capability.

**Support requirement.** The support requirement is negligible. A daily reporting requirement for all licensed vessels is important in monitoring catch rates, and this presupposes the possession of radio and operators by the fisheries authority. In the very worst case in which no such authority existed on a very remote island, a ship-to-shore transmission can be routed into the telephone system.

**Particular shortcomings.** This is an entirely random system which relies upon too many chance factors to be a reliable sole means of deterring illegal fishing.
On board inspectors and other personnel based approaches

In the face of the mass of technological approaches to the problem of resource policing, obvious and simple solutions are likely to be overlooked. The personnel based approach has a particular value in two applications, on the high seas where the regulations to be policed are a matter of treaty law, and ashore, where examination of the catch may reveal unlawful behaviour.

On board inspectors are of less value in the control of infringements of domestic law in EEZs. An inspector can only be on one vessel at any one time, and while that may be acceptable for fisheries surrounding islands for which only a few vessels are likely to be licensed at any one time, where there are a number of vessels operating simultaneously, such as the squid jiggers in the Atlantic sector of the Southern Ocean, the number of inspectors required is likely to be high. Moreover, for the degree of examination required, occasional visits, particularly frequent and irregular visits by fewer officers, will suffice.

The role of the onboard inspector can be a difficult one. It requires a measure of credibility derived from knowledge and experience, as well as his legal authority. The inspector needs to be the kind of individual who will deal diplomatically with the fishermen, but nonetheless uphold the regulations 'without fear or favour'. For someone who is a permanent guest on board a vessel, and dependant upon the crew for his accommodation and victualling, this can create undesirable tension.
Recent revelations by A V Yablokov regarding the Russian whaling in the 1960's highlight the shortcomings of systems utilising on board inspectors. Catch figures were under-reported by an order of magnitude by at least one of the four Russian whaling vessels operating in the Southern Ocean at the time. Authorised officials were on board, but to evade the regulations, Russia and Japan had simply exchanged inspectors (Papastavrou, 1994, p.46).

For single vessels operating alone in distant waters and in small numbers, such as whaling vessels, inspectors, providing their integrity can be relied upon, are an attractive option. They can certainly preclude the transshipment of cargo at sea. In cases in which they are applying treaty law, and their authority extends only to the submission of reports, they may be the only option available, as states are unlikely to respond favourably to requests by fellow treaty signatories for random boarding and inspection of their flag vessels.

The trade in marine products forbidden by treaty law can also be addressed by organisations operating ashore. Typical among these is Trades Records Analysis of Flora and Fauna in Commerce (TRAFFIC), which has some 17 offices worldwide, and which both monitors and acts to reduce the trade in biological items prohibited by treaty (Nash, personal communication, 1994, TRAFFIC International, 1993). These may include live animals, skins, horn and other products where the effect of the trade is to endanger particular species. Whalemeat is one of the items within its domain of interest.
Monitoring is accomplished by such means as the scrutiny of trade statistics and observation of ports and docks.

Such methods can be sophisticated. Greenpeace has used DNA analysis to identify the species from which particular samples of whalemeat has been derived, enabling them to prove that the tissue was derived from a species caught in contravention of standing regulations (Nash, personal communication, op. cit.)

**Detection capability.** Not applicable to this technique.

**Search efficiency.** With the cooperation of the crew of the host vessel, an inspector might manage to board and inspect another vessel, having detected it by chance. The odds in favour of this occurrence may be higher than the purely random since the host vessel will be operating in an area in which fishing for a particular species is likely to be successful, and other vessels may well therefore be in the vicinity.

**System availability.** For EEZ inspection, suitable individuals would have to be recruited. In the case of CCAMLR and the IWC, inspection systems are already in operation. Qualified personnel are available with experience in marine biology and the maritime world.

**Timeliness of data.** Infractions are instantly detected, but only for the host vessel.

**Capacity to make inspection.** This is inherent in the nature of the technique, but effectively limited to a single vessel.

**Ability to arrest.** This is applicable to EEZ protection, as it is unlikely that a flag state will authorise a foreign national to arrest one of its vessels, even if it is in
contravention of domestic law passed in compliance with treaty obligations. A fisheries officer from a coastal state might well be empowered to arrest a visiting vessel for infractions in an EEZ. Whether he can enforce that arrest is questionable.

**Support requirement.** This would be minimal since it can be made a condition of licensing that an inspector is carried and his accommodation and victuals are provided. For treaty enforcement, reasonable payment might be anticipated for the domestic upkeep of the inspector on board. Salary could be by short term contract, but reasonable terms would be needed to attract individuals of appropriate age and experience.

**Particular shortcomings.** This is an inflexible approach which concentrates too much of a specialist’s time in one area for EEZ applications. The inspector does not operate from a position of strength, despite his authority, as he is effectively alone and the guest of the vessel.
SECTION IX: CONCLUSIONS - A COMPARISON OF RIVAL APPROACHES

In view of the challenging requirements of a policing system for living marine resources, and the unique difficulties imposed by the Southern Ocean environment, it is hardly surprising that none of the rival approaches to the problem reviewed above emerges as a clear solution. The final complicating element is that having identified a promising approach or technology, the issue of cost inevitably forces a compromise on the fisheries authority. The compromises which may be acceptable in temperate or equatorial zones will not be solutions in the Southern Ocean. By the same token, a government or alliance attempting to undertake such policing, is not alone in facing financial and economic constraints. The fisherman intending to act illegally also faces a requirement to produce a profit, and although the remoteness and extent of the Southern Ocean favours him, it also raises his operating costs and erodes any profit margin. Disobedience to fisheries regulations is only attractive when there is a profit attached to it.

Of the surveillance technologies, most cover a single EEZ, and for remote islands or groups of small islands, this would prove expensive. The most promising surveillance system is satellite remote sensing, utilising synthetic aperture radar. This does not provide continuous coverage, but can give reasonably timely and predictable, if irregular, coverage of an area. It is certainly the only system which offers in the foreseeable future the potential to address the problem of the high seas, and the frequency of coverage will improve as more satellites are launched.
In the mean time, a minimal cost solution remains in the form of light aircraft, for the larger islands, and irregular ship patrols in other cases.

There does not appear to be any technical solution which combines high speed in a surface craft, or true amphibious capability in an aircraft, which can be expected to withstand Southern Ocean weather conditions. Consequently, there does not appear to be a compensating benefit to a policy of investing in a high speed surface craft which offsets the cost of both a surveillance and enforcement technology.

As boarding capacity and enforcement are the minimal requirement in the Peri-Antarctic EEZs, the limited surveillance of a patrol vessel may have to suffice where financial resources are strictly limited. To a great extent, knowledge of the local fishing grounds minimises the theoretical search requirement, and the establishment of a historical database of catch statistics is important in good fisheries management. It is important also to collect marine biological information, and that is something an aircraft does only inadequately. A patrol vessel, operating without the constraints of commercial interest, can collect data in a methodical and thorough fashion, combining the task to a certain extent with enforcement duties.

Speed advantage over fishing craft is important in a patrol vessel; however, a purpose built vessel will almost inevitably be more costly than the purchase an existing ship. The use of an existing vessel is a useful approach provided that the vessel is manufactured to suitable standards, sound, sea kindly, and capable of at least matching the speeds of
fishing vessels. This approach has been adopted by the French for the policing of Kerguelen, utilising a former trawler. Such a vessel is an attractive option, if well chosen. Desirable additional features are high capacity pumps, fire fighting equipment, a well equipped sick bay and some cargo capability. As speed is being sacrificed, it should be provided with a light, cheap and reliable weapon, which is sufficiently accurate to miss when required.

The biomarine policing requirement may be described as three distinct geographical areas which present separate legal and environmental problems. These will be examined in turn, with comments and possible solutions presented for each.

The high seas environment. As this is governed by treaty law, the requirement is for policing without enforcement in the traditional sense. Since high seas fishing is a right, the most that can be expected is the censure of other member nations within treaty organisations such as CCAMLR and the IWC. On board inspectors have an important role to play in this work, but careful selection of individuals will be needed to overcome the legacy of distrust which has grown up regarding this approach.

The full effects of high seas fishing outside the constraints proposed by CCAMLR are difficult to predict, although the damage to the species of true fish, krill and cephalopods may be of limited significance. The same is not the case with cetaceans. Where it is intended to preserve these species, the only surveillance system with the capability to operate under all weather conditions is synthetic aperture radar flown in satellites. This technology is likely to be available in the next decade, although the cost
of data capture and interpretation will not be insignificant. In addition to existing ground stations at O'Higgins, Syowa and Hobart, reasonably comprehensive coverage will be achieved by the addition of the planned station in South Africa, and receivers at Kerguelen and McMurdo Scott (Figure 22).

Although the judicious use of satellite radar imaging may reveal illegal whaling vessels through observation of contact behaviour and elimination of tracks known to be engaged in legitimate tasks, the problem of identification remains. Some assistance may be obtained from national authorities on formal request, but there may also be a role for non-government organisations here, in particular those with developed expertise resource bases, such as TRAFFIC and Greenpeace.

Peri-Antarctic islands with an infrastructure. The use of light fixed wing aircraft offers considerable economy for EEZ surveillance over competing systems. The added benefit of the potential to arrest, and the visible deterrent of the machine itself, gives it an attraction not enjoyed by some other surveillance systems.

For enforcement, a monohull patrol vessel is probably the most cost effective solution. Purpose built patrol vessels are likely to have a higher daily running cost than ex-commercial vessels such as oil rig support vessels, or trawlers purchased from existing owners. Short term costs can be reduced by hiring vessels, dramatically so if non-European vessels and crew are utilised, but this is unlikely to be acceptable for government use as they are not flagged to the coastal state, despite their authority as fisheries vessels. The solution to long term cost reduction may well be found by the
outright purchase of an appropriate vessel, and the minimisation of modification, complemented establishment and major overhaul. The utility of such a platform in secondary roles, and its value as an icon of coastal state authority are considerable.

In the long term, attention should be paid to the potential of satellite remote sensing for surveillance, although transponder systems are likely to have less value in the Southern Ocean environment.

**Peri-Antarctic islands without an infrastructure.** Where these are not too far removed from islands owned by a coastal state and which have an infrastructure, a policy of random patrols by surface vessels is likely to be the best which can be achieved at the least cost. Again, in the long term, satellite surveillance is likely to give warning of trespassing vessels in remote locations.

Collaborative alliances may solve some of the more extreme problems of remoteness. For example, satellite data collected and analyzed at Syowa revealing unauthorised activity around Heard Island might bring investigation by a French vessel bearing an Australian naval exchange officer authorised to act as a fisheries officer. Such an approach would mirror the collaborative efforts of organisations such as Interpol, and would reflect the intention on the part of governments to uphold their joint responsibilities under CCAMLR.
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APPENDIX A: DISTANT WATER FISHING METHODS

Four methods of catching will be described; trawling, long-lining, jigging and creeling. Some of the details were researched in connection with UK vessels, but the general principles are likely to remain the same, particularly with regard to enforcement issues.

Trawling. Distant water stern trawlers exceed 33m in length. They are fitted with a working deck and stern ramp for hauling nets on board. They may well be fitted with sophisticated sonar equipment for the detection of fish, and perhaps sensors on the trawl gear. Much of the fishing gear on board is automated and operated by a Trawlmaster. The trawl net is towed on two warps attached to twin winches (Figure 24). The netted catch is brought aboard and emptied into a fish tank on the deck below via a hydraulic hatch. The fish tank empties via ports on to a gutting line where the catch is manually gutted, before proceeding via a conveyor belt to a heading machine. The fish are then frozen into blocks in blast freezers (cold air blast), or plate freezers (chilled plates) which are more rapid, and placed in the hold. Some 50 tons of fish per day can be processed, and the crew, who may be working on a 'shares' scheme (percentage profit remuneration system) will sometimes work to the point of exhaustion. A typical European stern trawler can accommodate some 2000-2500 tons of catch. In a fleet system, a number of catcher boats offload to a factory vessel, which processes the catch, before offloading to a reefer. Large factory trawlers may both harvest and process the catch.

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Although designed to operate mid water for pelagic species. The mid water trawl can be taken down to within a metre of the seabed and certain alterations can be made to the trawl enabling it to come in to contact with the bottom. NOTE: At no time must the trawl door touch the bottom.

Figure 24: Pelagic Trawling. (Sea Fish Industry Authority, undated).
Krill are harvested by trawling, using a fine mesh net which lines an outer trawl. One method reported by Suzuki (1981, p.219-222) involves a factory vessel of some 9000t, supplied by catcher vessel(s) of some 1000t. Krill decompose rapidly once killed. Heaping of the catch, and the motion of the vessel, damage the fragile bodies including the cephalothorax in which the liver and stomach of the animal are located. The intestinal tract contains protease, and once ruptured, this attacks the surrounding tissues. As catching is discontinuous, and on-board processing proceeds at a finite rate, krill may be stored in a stocking pool filled with sea water. Bycatch species are manually removed on a conveyor belt. Krill have been tested in a number of products from frozen boiled whole krill to completely processed foods including protein paste, textured protein concentrate, minced meat block, and dried products.

The processing of the catch prior to freezing will therefore depend on the desired end product. Processing might well involve the removal of the cephalothorax to reduce decomposition, and peeling. The most effective method for achieving this is with peeling machines operating on a roller principle, in which raw krill and seawater are poured on to twin rotating drums or a single drum with an associated rubber belt. Fixed knives remove the shell, and the meat is collected. Heating stabilises the product. A Russian proposal for a ship borne installation for krill paste manufacture is noted by Suzuki. This system consists of twin machines, each with a joint capacity of 35-40 tons per day. Each plant consists of twin roller meat separators, a heating tank and a kneading unit.
**Long-lining.** A longline is essentially a main line to which smaller hooked lines or 'snoods' are attached at regular intervals. A longline can be up to ten miles in length, with as many as 50,000 hooks. It is anchored and buoyed at both ends. The Russian system is a simple autoline, which can be shot rapidly. The Spanish system, which is also in use in the Southern Ocean, utilises a main line, to which are attached at regular intervals, weights and lines which in turn are connected by clips to a monofilament (Figure 25). This monofilament takes the snoods, which are manually baited in groups of 70 hooks. Longlining is undertaken at constant depths making it possible to locate longliners by following isobaths (Parkes, 1994, personal communication).

**Jigging.** Jigging is a system of fishing which exploits the natural voracity of the squid. Weighted lines fitted with squid hooks and underwater lamps are suspended over the side from mechanically driven spools (Figure 26). The mechanism causes the lines to oscillate in a vertical plane. The squid, attracted by the light and the moving lures, are snared on the hooks and reeled onboard where the machine flips them onto a collecting net. Automatic jigging machines can be fitted with single or twin drums, and a vessel of some 100 tons might be fitted with 20 such machines. A 500 ton vessel could have a typical outfit of 60 machines. Once brought onboard, the squid are transferred below, perhaps by conveyor belt, to be processed and frozen (Hind, 1994, personal communication). Jigging is conducted from well lit vessels at night.
Figure 25: Longlining systems. (From an original drawing by Dr G Parkes, 1994).
Figure 26: Squid jigging system of the type used in the Southern Ocean. (drawing by author based on information provided by J Hind, 1994).
Creeling. Creeling or potting is conducted using a line buoyed at both ends, to which are attached baited cages with apertures by which a crustacean can enter, but not leave. It is the only form of bottom fishing for crustaceans presently permitted by CCAMLR.

Russian fishing fleet organisation. The Soviet fishing fleet was an elaborate commercial enterprise with a number of components:

**SOVIET FISHING FLEET SYSTEM**

Trawlers. 2000-3000 GRT, or 3000-4500 GRT (FAO category 10 and 11 respectively).

Longliners. 630-650 GRT. Generally converted stern trawlers, fitted with Norwegian autoliners (automatically baited lines).

Reefers or supply vessels. 5000-15000 GRT. Transport replacement crew and spare parts to the fleet and return with the catch. A reefer is a refrigeration vessel in UK maritime parlance (Kilvington, 1994, personal communication).

Tankers. Refuel vessels in the fleet. Also used for the supply of oils and lubricants.

Ocean-going tugs. Assist vessels in distress. Outfitted to undertake major repairs.

Research vessels. Conduct marine biology, oceanography and similar research in direct support of the fishing fleet. Additionally, these vessels undertook the detection of fish and other species for the fleet, and research into catching and processing technology.

The detection task is now no longer undertaken.

(After Kock 1992, p.204-206. Tonnages are approximate).
APPENDIX B: ANTARCTIC TREATY SIGNATORIES

The symbol # denotes a member with an EEZ which lies within the area of the Southern Ocean as defined in Section II. The symbol CC denotes a member of CCAMLR. CA denotes nations that have acceded to the Convention, but are not members of the Commission.
### TABLE 3: MEMBERSHIP OF THE ANTARCTIC TREATY AND CCAMLR

<table>
<thead>
<tr>
<th>Original Consultative Parties</th>
<th>Later Consultative Parties</th>
<th>Non-consultative parties</th>
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<td>Brazil</td>
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<td>Australia</td>
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<td>Slovak Republic ³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switzerland</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ukraine</td>
</tr>
</tbody>
</table>

1 Succeeded as the Soviet Union.
2 Succeeded before the unification of Germany.
3 Succeeded to the Treaty as Czechoslovakia.
4 Succeeded following independence from Australia.
In addition, the European Economic Community is a member of CCAMLR. (Headland, 1993).
In addition, the European Economic Community is a member of CCAMLR. (Headland, 1993).
Scott Polar Research Institute

Argentine limits — [25° to 74°W, 60°S]
British limits — [20° to 80°W, 60°S]
Chilean limits — [53° to 90°W, unspecified northern limit]
Undefined limits

NATIONAL TERRITORIES DEFINED SOUTH OF 60°S IN THE YEAR AFTER THE TREATY CAME INTO FORCE (1962)

YEAR OF TERRITORIAL DEFINITIONS: British Antarctic Territory 1908 (as Falkland Islands Dependencies, amended 1917; differentiated 1962), Ross Dependency 1923, Terre Adélie 1924 (delimited 1938), Peter I Oy 1931, Australian Antarctic Territory 1933, Dronning Maud Land 1939, Territorio Chileno Antártico 1940, Antártida Argentina 1943 (extended 1947)

[R. K. Headland 1 - III - 1994]

Figure 27: Sovereign claims in the Antarctic Treaty region. (Headland, 1994b).
APPENDIX C: SEARCH EFFICIENCY CALCULATIONS

When the surveillance of a given resource area is dependant upon a sensor carried by a platform, the efficiency of the search is proportional to the capacity of the given platform to bring a defined area within its sensor range in a specified time. To obtain some measure of comparative search efficiency, generic candidate platforms are compared using a test case devised for this thesis.

The sensor ranges are assumed to be related to either visual search, or radar search. In the case of radar, line of sight forms the basis of the range estimate. This is controlled exclusively by sensor and target height, using the conventional formula for this purpose (Rohan, 1983, p194):

\[
R = (4.12 \times H_s^{1/2}) + (4.12 \times H_t^{1/2})
\]

Where:

- \( R \) = Range in kilometres
- \( H_s \) = Height of sensor in metres
- \( H_t \) = Height of target in metres

It is assumed here that the target is at sea level, and attains its complete radar reflecting area instantly when approaching the observer across the horizon, thereby eliminating any uncertainties associated with the gradual exposure of a ship target of indeterminate aspect. Performance limitations related to propagation are also ignored.
In an environment in which rain, snow and high seas are common, this is anything but a realistic assumption, and it made here for no other purpose than to achieve conditions for the objective comparison of candidate technologies. To support these assumptions, specimen calculations for generic radar performance appropriate to this study are given in Appendix D. Similar calculations for visual detection are at Appendix E.

The test scenario for the evaluation of candidate platform/sensor combinations is a peri-Antarctic island surrounded by an EEZ of 200nm radius. The area is searched by repeated regular parallel sweeps. The island is a point without extension, and no allowance in track deviation need be made for it irrespective of platform type. The issue of the transit to and from the search pattern terminals by the platform, whether it is based on the island or elsewhere, is eliminated from the calculations in order to equalise conditions between candidate platforms. It is nonetheless an issue considered in the text.

Four variables govern the search; area size, sensor range, search platform speed, and fishing vessel speed. To outline the problem of determining the relationship between these four elements, an exemplary case would consist of a rectangular area of length $A$ and width $B$ which has to be searched by a platform using the strategy of parallel straight search legs cited above ($P_1...P_n$).

<table>
<thead>
<tr>
<th>Start $P_1$</th>
<th>$\longrightarrow$</th>
<th>$\longrightarrow$</th>
<th>$P_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_4$</td>
<td>*------------------</td>
<td>$\longleftrightarrow$</td>
<td>$P_3$</td>
</tr>
<tr>
<td>$P_5$</td>
<td>$\longrightarrow$</td>
<td>$\longrightarrow$</td>
<td>$B$</td>
</tr>
</tbody>
</table>

99
The distance between these legs is determined by the sensor range, $S$, which is reduced by an overlap of width $W$. The overlap represents the maximum distance the fishing vessel may move in the time taken for the search platform to complete 2 adjacent legs plus the distance between them. In the worst case, a fishing vessel at the edge of the area from which the platform begins, proceeds at maximum speed on a course perpendicular to the axis of the search, on a path which crosses the stern of the search platform. In the diagram above, this is represented by the asterisk, which may be supposed to lie immediately to the south of the search swath during the sweep P1 to P2. Once the search platform has passed, the vessel then proceeds directly north. The problem is therefore to ensure that the conduct of the search is such that the track is not missed.

The track length of the search may be characterised by:

$$D = 2A + S - \frac{W}{V_p}$$

(2)

Where:

- $D$ = Distance covered by the platform
- $A$ = Length of area
- $S$ = Swath width ($2 \times$ sensor range).
- $W$ = Distance moved by fishing vessel during search leg
- $V_p$ = Platform speed

From this it follows:

$$W = (2A + S - W)V_t/V_p$$

(3)

Where:

- $V_t$ = Fishing vessel speed
Which may be rewritten:

\[
W = \frac{(2A + S)V_t}{V_p + V_t}
\]  

(4)

For this rectangular search, the distances and times required to complete the area \( A \times B \) may be determined by analysis of the number of sweeps which constitute the search:

<table>
<thead>
<tr>
<th>Number of sweeps</th>
<th>total distance</th>
<th>Width covered (x/B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (P1 to P2)</td>
<td>A</td>
<td>S</td>
</tr>
<tr>
<td>2 (P1 to P4)</td>
<td>(2A + S - W)</td>
<td>(2S - W)</td>
</tr>
<tr>
<td>3 (P1 to P6)</td>
<td>(3A + 2(S - W))</td>
<td>(3S - 2W)</td>
</tr>
</tbody>
</table>

From this table, it will be seen that to complete a given number of legs (n), the distance involved is:

\[nA + (n - 1)*(S - W)\]  

(5)

Which will require a search duration of:

\[\frac{nA + (n - 1)*(S - W)}{V_p}\]  

(6)

The total width of the area covered will be:

\[nS - (n-1)W\]  

(7)

It follows that whatever the width B to be covered, the value of n is chosen such that the result of (7) equals or exceeds B.

The case of a circular search area, such as the hypothetical EEZ in the test case, is rather more complex. The value of A varies throughout the search, although in a
predictable manner. With this fluctuation in A, there will inevitably be variation in the width of the safety overlap, W. This problem has been addressed by the use of a computer program. The variables are represented in the form of fractions, enabling the values to be changed as required. The output from the program, which analyses total search distance as a function of the search radius of the circle, is given below. Division of the total search distance by the platform speed gives the total search time.

**TABLE 4: TOTAL SEARCH DISTANCES AS A FUNCTION OF RADIUS FOR CIRCULAR AREAS**

<table>
<thead>
<tr>
<th>Vt/Vp</th>
<th>S/R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>0.0</td>
<td>35.4</td>
</tr>
<tr>
<td>0.01</td>
<td>54.2</td>
</tr>
<tr>
<td>0.02</td>
<td>46.5</td>
</tr>
<tr>
<td>0.03</td>
<td>89.4</td>
</tr>
<tr>
<td>0.04</td>
<td>70.5</td>
</tr>
<tr>
<td>0.05</td>
<td>58.7</td>
</tr>
<tr>
<td>0.06</td>
<td>51.4</td>
</tr>
<tr>
<td>0.07</td>
<td>46.0</td>
</tr>
<tr>
<td>0.08</td>
<td>88.5</td>
</tr>
<tr>
<td>0.09</td>
<td>71.8</td>
</tr>
<tr>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

S = Swath width (2 * sensor range)

R = Search area radius
Vp = Search platform speed  
Vt = Fishing vessel speed

Blank areas in the table indicate combinations of parameters for which no solution exists.

Considering the candidate vehicles for enforcement, this method of comparison yields the following results:

**TABLE 5: COMPARISON OF CANDIDATE PLATFORM PERFORMANCE**

<table>
<thead>
<tr>
<th>Platform</th>
<th>Vp (kts)</th>
<th>Hs (m)</th>
<th>S (nm)</th>
<th>Area searched ( \text{nm}^2 \text{ hr}^{-1} )</th>
<th>D (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light aircraft</td>
<td>128</td>
<td>457</td>
<td>95</td>
<td>12160</td>
<td>5010</td>
</tr>
<tr>
<td>Helicopter</td>
<td>132</td>
<td>457</td>
<td>95</td>
<td>12540</td>
<td>5010</td>
</tr>
<tr>
<td>Ship</td>
<td>12</td>
<td>20</td>
<td>20</td>
<td>240</td>
<td>no solution</td>
</tr>
<tr>
<td>Hovercraft</td>
<td>50</td>
<td>9</td>
<td>13</td>
<td>650</td>
<td>no solution</td>
</tr>
<tr>
<td>Hydrofoil</td>
<td>43</td>
<td>11</td>
<td>15</td>
<td>645</td>
<td>no solution</td>
</tr>
<tr>
<td>Ekranoplan(^1)</td>
<td>216</td>
<td>18</td>
<td>19</td>
<td>4104</td>
<td>no solution</td>
</tr>
<tr>
<td>Airship</td>
<td>50</td>
<td>457</td>
<td>94</td>
<td>4700</td>
<td>no solution</td>
</tr>
</tbody>
</table>

\(^1\) (Wing-in-ground-effect aircraft).

Assumptions:

Vt = 10kts  
Hs = height of sensor (m)  
S = swath width (2 * sensor range, calculated on line of sight)  
D = Distance covered to search a circular area of 200nm radius.
By this evaluation, only the aircraft have sufficient advantage in sensor range and speed to undertake the task as defined. Neither has the endurance to search the entire area in a single day. The light aircraft can cover 11%, and the helicopter 15.8% respectively. The surprising result is the Ekranoplan, which has speed advantage, but poor sensor range, based on line of sight. The sensor height is based on published photographs. If the aircraft can fly at 128m, it can obtain a solution. The ship can never hope to conduct a systematic search against a moving fishing vessel, at the representative speeds considered. Its worth effectively lies in its nuisance value against vessels engaged in illegal fishing and either stationary or at slow speed.
APPENDIX D: RADAR DETECTION CALCULATIONS

There are three cases of radar detection which require to be validated against line of sight ranges. These are:

a. A coastal radar sited on a peri-Antarctic island.

b. An airborne radar.

c. A radar mounted upon a surface vessel.

For these cases, the line of sight range will be as follows:

a. Coastal radar. Where antenna height is equal to the mean average greatest height for peri-Antarctic islands north of 60°S (derived from Headland, 1994c).

\[ R = 4.12 \times 1129^{1/2} = 138.434\text{km} \]

b. Airborne radar. Patrol altitude 610m (English, 1986):

\[ R = 4.12 \times 610^{1/2} = 101.756\text{km} \]

c. Surface vessel radar. Height of mast 20m.

\[ R = 4.12 \times 20^{1/2} = 18.425\text{km} \]

The Radar equation, modified from Rohan, (1983, p.98) is:

\[
R = \sqrt{\frac{P \times A^2 \times Ra}{4 \times \pi \times l^2 \times k \times T \times B \times F \times L1 \times L2 \times (SN)}}
\]

Where:

P = Transmitter power (W).

A = Antenna effective area (m).
\[ Ra = \text{Target echo area (m}^2\text{). 85m}^2 \text{ is assumed for a distant water fishing vessel of average size.} \]

\[ l = \text{Wavelength (m).} \]

\[ k = \text{Boltzmann's constant (1.38 \times 10^{-23} J/K).} \]

\[ T = \text{Absolute temperature of the receiver, conventionally 290K.} \]

\[ B = \text{Bandwidth, usually specified in radar design as 3dB.} \]

\[ F = \text{Receiver noise temperature. An average figure has been assumed after Shibuya, 1987, p.441) of 26.5K.} \]

\[ L_1 = \text{System losses. Typically, 16dB (Rohan, 1983, p.94).} \]

\[ L_2 = \text{Atmospheric losses.} \]

\[ (SN) = \text{Signal to noise ratio, for a given set of detection parameters. In this case, it has been assumed that 20 hits per scan are required on the target to ensure good subclutter visibility (Rohan, 1983, p.98). The Probability of detection and the Probability of false alarm respectively were chosen as 0.5 and } 10^{-6}, \text{ after an example by Rohan, (1983, p.270). With the noncoherent integration of pulses, and a target of Swerling case 1 fluctuation, this gives a signal to noise ratio of 3dB (Blake, 1980, p.48).} \]

Rewriting equation 8, the losses for atmospheric propagation can be isolated:

\[
L_2 = \frac{P \cdot A_2 \cdot Ra}{4 \cdot \pi \cdot l^2 \cdot k \cdot T \cdot B \cdot F \cdot L_1 \cdot R^4 \cdot (SN)}
\]  \hspace{1cm} (9)

Taking the numerical values for the above factors, we have:
\[ L_2 = \frac{P \cdot A^2 \cdot 85}{(7.968 \cdot 10^{-18}) \cdot 12 \cdot R^4} \]

A frequency in the I/J band is a reasonable assumption for all of these sensors, although the transmitter power and antenna size will be commensurate with the platforms. Equation 9 may now be rewritten:

\[ L_2 = \frac{P \cdot A^2 \cdot 85}{(2.112 \cdot 10^{-19}) \cdot R^4} \]

This may be applied to the individual cases, using attenuation figures from Shibuya, (1987, p.344) as follows:

**Coastal radar.** \( R = 138.434 \text{km} \). Antenna diameter is 1.2m, giving an effective area of .6m\(^2\) at 55\% efficiency. Peak power is 200kW.

\[ L_2 = \frac{P \cdot A^2 \cdot 85}{(2.112 \cdot 10^{-19}) \cdot (3.673 \cdot 10^{20})} = \frac{77.574}{L_2} = 78892.412 = 49 \text{dB} \]

Giving a potential range in \( O_2 \) and water vapour attenuation of 1408km, which reduces to 59km in rain falling at a rate of 25mm hr\(^{-1}\).

**Airborne radar.** \( R = 101.756 \text{km} \). Antenna diameter is 0.5m, giving an effective area of .1m\(^2\) at 55\% efficiency. Peak power is 8kW.
\[
L_2 = P \times A^2 \times 85 \\
\frac{(2.112 \times 10^{-19}) \times (1.072 \times 10^{20})}{22.641}
\]

\[
L_2 = P \times A^2 \times 85 \\
\frac{0.024}{0.024}
\]

\[
L_2 = 300.34 = 25\text{dB}
\]

Giving a potential range in $O_2$ and water vapour attenuation of 718km, which reduces to 30km in rain falling at a rate of 25mm hr$^{-1}$.

Surface vessel radar. $R = 18.425$km. Antenna diameter is 0.5m, giving an effective area of $0.1m^2$ at 55% efficiency. Peak power is 3kW.

\[
L_2 = P \times A^2 \times 85 \\
\frac{(2.112 \times 10^{-19}) \times (1.153 \times 10^{17})}{0.024}
\]

\[
L_2 = 106250 = 50\text{dB}
\]

Giving a potential range in $O_2$ and water vapour attenuation of 1437km, which reduces to 60km in rain falling at a rate of 25mm hr$^{-1}$.

The above systems assume peak power ratings and antenna diameters typical for their class. Antenna sizes have been calculated from Shibuya, (1987, p.154) assuming parabolic geometry. It has been assumed that for this application, these systems would have either MTI or Doppler discrimination processing against clutter. Clutter calculations have therefore not been undertaken.
APPENDIX E: VISUAL DETECTION CALCULATIONS

As with any of the electromagnetic or acoustic methods of detection, visual detection is a far from simple process to quantify in simple mathematical terms. Given fundamental provisions of visual acuity and illumination, the critical factor is contrast, which can be quantified as a ratio of a given object or surface, and its background. The result is expressed as a percentage:

\[ C = \frac{(R_{\text{max}} - R_{\text{min}}) \times 100}{(R_{\text{max}} + R_{\text{min}})} \]  

(10)

Where:

\[ C \quad \text{Contrast (\%)} \]

\[ R_{\text{max}} \quad \text{Reflectance of the brighter object or surface} \]

\[ R_{\text{min}} \quad \text{Reflectance of the fainter object or surface} \]

The terms \( R_{\text{max}} \) and \( R_{\text{min}} \) are applied irrespective of whether they apply to the object or background. The scale of reflectance has at its extremes 1.0 (white) and 0.0 (black). In practice, both qualities are rarely observed with absolute clarity, as haze, mist, rain and atmospheric pollutants obscure the light path from the subject to the observer. The perfect degree of contrast, 100\%, is therefore very unlikely to be achieved.

A fundamental level of illumination is required for visual perception, a quantity in excess of 100 lux (150mW m\(^2\) 0.55\(\mu\)m wavelength). Having met this requirement, judgements may be made regarding the minimum angle the eye can discern for a given contrast value. Representative figures are:
From the minimum angle of perception, the visual range of a given target can be deduced. In the case of fishing vessels, determining a reasonable average figure for contrast is by no means straightforward. Specimen photographs of fishing vessels typical for the Southern Ocean reveal a range of paint schemes; although white superstructure, particularly at the centrecastle, and a black or dark hull seem common, so too is the weatherbeaten appearance of distant water working vessels, which tends to reduce the contrast. Contrast levels are dramatically altered by vessel aspect, solar altitude, and the meteorological conditions. A change in course, coupled with a low altitude sun at sub-polar latitudes, can suddenly present the observer with a bright point of reflected glare.

For the purposes of this study, it has been decided that the predominant feature of a fishing vessel is its dark hull - contrasting with reflected light on the sea surface when
viewed from the air, or contrasting with a brighter horizon when viewed from another surface vessel. As air observation potentially provides the greatest range, the following parameters are proposed:

Line of sight range for comparison, based on an observation altitude of 610m (English, 1986):

\[ R = 4.12 \times 610^{1/2} = 101.756 \text{km} \]

(11)

Target size, based on a root mean square calculation based on a vessel 65m long, 12m high, and 18.5m beam, giving an all aspect figure of 39.6m².

Contrast, using: hull = 0.1

\[
\frac{0.3 - 0.1}{0.3 + 0.1} \times 100 = 50\%
\]

Reduced for atmospheric effects by 30% total, giving 35%, for which the human perception is some 1.25 arcmin.

Then:

\[
R = \frac{39.6}{\sin 1.25'} = 108.9 \text{km}
\]

Although generalised, this suggests that visual detection will be possible to the line of sight horizon in average conditions.

(Calculations based on information provided as Rees, personal communication, 1994)
APPENDIX F: ACOUSTIC DETECTION CALCULATIONS

The calculations in this section are, as with the other sections, an examination of the generic case. Examples of this technology are few in the open literature and the information presented here is derived almost exclusively from a manufacturer’s brochure for a seabed passive array for monitoring fishing activity in an exclusive economic zone (the other source consulted was *Jane’s Underwater Systems* 1993/1994). The illustration provided here assumes the generic peri-Antarctic island used for the radar calculations; a mean averaging of the properties of the islands north of 60° south given by Headland (1994c). The area of the island is 451.342km², giving a radius of 11.986km² which will be taken as 12km.

The manufacturer’s data gives the following parameters:

- Number of arrays. 2 - 3
- Number of hydrophones in a single array. 64 - 256
- Array length. 160 - 1800m
- Coverage in standard weather conditions (sea state 3 - 4), small fishing vessels, noise radiation level 1 Pa/(Hz)^{1/2}. 200km.

The detection range against the specimen target is quoted for a shallow sea installation, with the arrays parallel to the shore line. A minimum system installation suggested in the manufacturer’s literature utilises an array baseline at a distance of 100km offshore, giving a total baseline circumference of 703.718km. With a prescribed spacing
of 100km between arrays, the total length of underwater cable required, irrespective of the number of shore cables, is 700km, feeding 7 arrays. As noted above, the system as described could provide continuous cover of not less than 87.3% of the EEZ (305365km²), provided that the quoted average range is correct.

No information regarding the frequency range of the equipment is provided. A minimum signal of $1 \text{ Pa}/(\text{Hz})^{1/2}$ is stated. At spectrum level, the equivalent noise from a minimally detectable fishing vessel would be:

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>10Hz</td>
<td>55dB</td>
</tr>
<tr>
<td>100Hz</td>
<td>50dB</td>
</tr>
<tr>
<td>1000Hz</td>
<td>45dB</td>
</tr>
<tr>
<td>10000Hz</td>
<td>40dB</td>
</tr>
</tbody>
</table>

At these levels, the system could not be expected to operate, at any of the above frequencies. This becomes clear when a more plausible case is assumed in which it is inferred that manufacturers' data are references to the minimum noise intensities at the array.

Taking the sonar equation for the passive case from Urick (1983):

$$\text{SL} - \text{TL} = \text{NL} - \text{DI} + \text{DT}$$

(12)

Where:

- $\text{SL} = \text{Source Level}$
- $\text{TL} = \text{Transmission Loss}$
- $\text{NL} = \text{Noise Level}$
\( DI = \) Directivity Index of the array
\( DT = \) Detection Threshold

When rewritten in terms of the noise intensity level at the array, this becomes:

\[
(SL - TL) = NL - DI + DT
\]  \hspace{1cm} (13)

We then have:

\( SL = \) Source Level, which may be deduced by summing transmission loss at the frequency of interest with given minimum noise levels at the array.

\( TL = \) Transmission Loss, from Urick, (1983, p.111), for a path length of \(2.187 \times 10^5\) yds (200km) this is calculated using spherical spreading and absorption loss using

\[
TL = 20 \log r + a r^* 10^{-3}.
\]  \hspace{1cm} (14)

\( r \) is in yards, and the absorption loss is read from graphical information.


\( DI = \) Directivity Index of the array. Calculated using the array length given in the specification, and the formula given by Urick (1983, p.43):

\[
DI = 10 \log \frac{2L}{\lambda}
\]  \hspace{1cm} (15)

\( DT = \) Detection Threshold. To be calculated, using:

\[
5 \log \frac{d_w}{m^2 \ t}
\]  \hspace{1cm} (16)
(Urick, 1983, p.397) Where \( d \) is the detection index, taken as 12 for a specimen case of probability of detection \((Pd)\) of 50\%, and probability of false alarm \((Pfa)\) of 0.05\% (chosen in the absence of other data to emulate human audition). \( w \) is the bandwidth, and \( t \) is the observation time in seconds. This formula is for uncorrelated noise where the number of hydrophones is known, as in this case.

Square law detection has been assumed.

Equation 12 may then be rewritten for the above frequencies:

\[
SL - TL = NL - DI + DT - DI - DT
\]

\[
\begin{align*}
10Hz & \quad 55dB \quad = \quad 72dB \quad8dB \quad + \quad (-9dB) \quad17dB \\
100Hz & \quad 50dB \quad = \quad 71dB-\quad 20dB \quad + \quad (-1dB) \quad21dB \\
1000Hz & \quad 45dB \quad = \quad 64dB-\quad 30dB \quad + \quad 11dB \quad19dB \\
10000Hz & \quad 40dB \quad = \quad 48dB-\quad 40dB \quad + \quad 32dB \quad 8dB
\end{align*}
\]

These figures, although mathematically plausible, correspond only approximately at medium frequencies with those given by Urick (1983, p.347) for a trawler.

\[
\begin{align*}
SL & \quad SL \ (Urick\ 1983) \\
100Hz & \quad 159dB \quad 151dB \\
1000Hz & \quad 170dB \quad 131dB
\end{align*}
\]

Although a disparity still exists in the calculations, it may be that the system is exploiting line components, which can be some 15dB or greater above the above the average radiated noise intensity (Urick, 1983, p.329, 340).
If the quoted performance figures are taken as read, there still remains the problem of environmental influence on the performance of the system. Although in the absence of frequency information it is not possible to give predictions of performance degradation, the effects of the environment - often more significant than in the case of radar, can be stated qualitatively.

The terms of the equation which reflect environmental conditions are ambient noise (NL) and propagation loss (PL). Although the ambient noise in the Southern Ocean is unlikely to be subject to sudden increases in noise generated by shipping, increases due to increases in wind generated noise may well increase by up to 3dB, that is, twice the noise intensity, (Knudsen, reported in Urick, 1983, p.210.) and noise due to rain in the band 100Hz to 10,000Hz which was examined above, can be influenced by intensities of 69dB to 76dB (Franz, reported in Urick, 1983, p.220).

Alterations in propagation loss due to oceanographic conditions can also be significant. Propagation loss can alter dramatically as the result of a number of factors, both physical, such as the depth of the receiving array, and oceanographic, such as a change in the sound velocity profile through the water column as the seasons alter. Etter (1991) notes two phenomena which give rise to oceanographic variability which are particularly relevant in this context. These are ocean fronts, and eddies.

The existence of both fronts and eddies in the Southern Ocean was noted in Section III. Fronts have a circumpolar distribution in the Antarctic. It is not possible without
specific data to quantify the extent of the acoustic effects associated with fronts, but some of their more significant effects are given below (Etter, 1991, p.33):

a. Differences in sonic layer depth of the order of 300m on opposite sides of the front, dependant upon the season. The duct acts as a waveguide, and its depth determines the frequency range of the acoustic energy trapped within it.

b. Changes in the sound velocity gradient both in and below the surface duct, which influences sound refraction.

c. A change in the depth of the sound channel axis, a region of low sound speed in the water column which traps and propagates sound. This can be some 750m when crossing from one water mass to the adjacent one.

d. An increase in biological activity, giving rise to increased ambient noise and reverberation.

e. An enhancement in air-sea interaction along the frontal zone, resulting in significant increases in sea state, and consequently ambient noise and surface roughness, which can alter reflection loss.

f. Refraction of sound at an oblique angle when passing through a front can result in bearing errors in sonar systems.

Etter characterises fronts into three classes, dependent upon their effect upon sound speed, upon the sonic layer depth, persistence, and depth. By this definition, the Southern Ocean has two fronts of moderate intensity south of the Subtropical Convergence which forms its northern extremity. These are the South Polar Front, or
Antarctic Convergence, and the Antarctic Divergence (Etter, 1991, p.33-35). A weak front to the south of New Zealand is also noted. The most important front in the context of the peri-Antarctic islands is the Antarctic Convergence. Although doubtless subject to seasonal variations in both position and characteristics, a median location given by a Hydrographic Office chart (Hydrographer of the Navy, Chart 4005, 1993) places it just to the south of Macquarie Island, and precisely coincident with Kerguelen.

The extensive distribution of eddies in the Southern Ocean, and their importance to the ecosystem, has been commented on in Section III. Eddies are bodies of dissimilar water entrained in an alien water mass. Their acoustic effects include the displacement of convergence zones in the sound field, horizontal refraction, and modification in multipath propagation sequences (Etter, 1991, p.153, 154). Eddies are frequently shed at fronts.

Two further oceanic effects which may be of significance to some peri-Antarctic island locations where seabed acoustic sensors are planned are internal waves, and the proximity of the ice edge. Internal waves are fluctuations in density surfaces in the water column. They are common over continental shelves, and are recognised as affecting acoustic propagation in the 50Hz to 20,000Hz spectrum. Internal waves limit the spatial and temporal stability of acoustic paths, and manifest themselves in amplitude and phase variations (Etter, 1991, p.37-39).

Where islands fall within the extent of the pack ice, such as the South Sandwich Islands, and where there is potential for fishing to extend south as the spring retreat of
the ice seeds the water, an enhancement in ambient noise associated with the marginal ice zone (MIZ) may result in a reduction in the signal to noise ratio under some circumstances. A distribution of the noise enhancement is reported across the frequency spectrum 100Hz to 1000Hz. (Etter, 1991, p.37-39).

Clearly, the manifestation of these phenomena may significantly affect both the choice of location and indeed, the decision whether it is desirable to utilise sea bed acoustic array technology for monitoring marine living resources at all.
APPENDIX G: RELATIVE COSTS OF SURVEILLANCE SYSTEMS AND PLATFORMS FOR MARITIME POLICING

The following information is presented in Sterling. It should be assumed that the prices refer only to the time of publication. In an attempt to eliminate commercial interests, sources of information have been cross-referred in some cases, and it should not be assumed that individuals and organisations referred to in the Acknowledgements are necessarily the sole references consulted.

The price information for the sea bed surveillance system was quoted in 1993, in US dollars. This has been converted, using a 2% rate of inflation and a conversion factor of $1.5 = £1.0. The equipment requirements for the surveillance systems were for the generic peri-Antarctic island referred to above, and the assumptions used were as follows:

HF Radar system.

One master transmitter/receiver and processing system, plus 3 arrays each with an arc of coverage of 120°. Total procurement cost, less operator training: £4,000,000

Sea bed surveillance system.

An array baseline of 703km circumference, utilising 7 acoustic arrays (the manufacturer’s proposed spacing):
7 arrays at $35,000  
7 special purpose units at $15,000  
35 repeater units at $10,000  
700km of cable at $1150 km⁻¹  
Data processing unit  
Remote power unit  
Software  
Installation, service and training  

Total, not including ship charter at customer’s expense:  
inflation (2%)  
Subtotal  
Converted to sterling  

$245,000  
$105,000  
$350,000  
$805,000  
$210,000  
$40,000  
$1,900,000  
$2,130,000  
$5,785,000  
$15,700  
$5,900,700  
£3,933,800  

The information is intended to give an indication of costs, and it should be borne in mind that not only are there sizeable additional factors in initial procurement, such as the erection of buildings and roads to operating sites, but through life costs can significantly alter the expense of particular systems. Moreover, there is no simple yardstick for the comparison of say, a radar which may be relied upon to cover the inner 50% of an EEZ continuously, and an aircraft which can cover the entire area in separate missions 5 times per week. It might be argued that the most important fisheries are likely to be within 100nm of a peri-Antarctic island, and that therefore the radar was a
better utilisation of the investment. However, the task might include simultaneous surveillance of an offlying island and its resources; each case needs to be judged on its own merits.

The following platform costs were obtained:

**TABLE 5: RELATIVE COSTS OF ENFORCEMENT VEHICLES**

<table>
<thead>
<tr>
<th>Platform</th>
<th>Initial cost</th>
<th>Direct operating cost</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic maritime patrol aircraft</td>
<td></td>
<td>2,627 hr⁻¹</td>
<td></td>
</tr>
<tr>
<td>Light fixed wing aircraft</td>
<td>600,000</td>
<td>125 hr⁻¹</td>
<td>assumes usage of 1000 hr yr⁻¹ Piston engine machine</td>
</tr>
<tr>
<td>Helicopter¹</td>
<td>10,000,000</td>
<td>33 hr⁻¹</td>
<td></td>
</tr>
<tr>
<td>Generic military helicopter</td>
<td></td>
<td>1,315 hr⁻¹</td>
<td></td>
</tr>
<tr>
<td>Generic frigate</td>
<td></td>
<td>91,800 dy⁻¹</td>
<td></td>
</tr>
<tr>
<td>Generic patrol boat</td>
<td></td>
<td>12,500 dy⁻¹</td>
<td></td>
</tr>
<tr>
<td>Fishery patrol vessel (converted trawler)</td>
<td></td>
<td>3,500 dy⁻¹</td>
<td></td>
</tr>
<tr>
<td>Hovercraft</td>
<td>3,000,000</td>
<td>60 hr⁻¹</td>
<td>assumes 2000 hr yr⁻¹ usage. Diesel propulsion</td>
</tr>
</tbody>
</table>

(Figures are in sterling)
The machine would be in the Sea King (S 61) class. A reconditioned machine might be had for some 4,500,000. A more modern equivalent such as the EH 101 costs 14,000,000.

The direct operating costs do not reflect additional expenses such crew and insurance. The method of costing the generic platforms was not revealed to the author.

It is estimated that a light aircraft would have a life of 20 years, while a new helicopter would last 30. A reconditioned helicopter might last from 10 - 15 years. A hovercraft of the type considered here has a useful life of 25 years. The HF radar described here is estimated to have a life of 25 years also. All the systems examined above would require maintenance by qualified personnel to achieve these estimates.

The daily cost of the fishery patrol vessel is a hire charge. There are three avenues for reducing costs with these vessels. The hire of non-western European vessels and crews, or the use of long term contracts, could reduce costs. Where it is known that the patrol requirement will persist, hire charges may be dispensed with altogether by the outright purchase of a suitable ship. However, to maintain the advantage, maximum use would have to be made of the vessel, modifications would need to be minimised, maintenance reduced to the minimum, and manning closely scrutinised.