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FISHING GROUND SELECTION IN THE ANTARCTIC KRILL FISHERY: TRENDS IN PATTERNS ACROSS YEARS, SEASONS AND NATIONS

S. Kawaguchi✉ and S. Nicol
Australian Government Antarctic Division
Department of Environment and Heritage
203 Channel Highway, Kingston 7050
Tasmania, Australia
Email – so.kawaguchi@aad.gov.au

K. Taki and M. Naganobu
National Research Institute of Far Seas Fisheries
2-12-4 Fukuura, Kanazawa-ku, Yokohama
Kanagawa, 236-8648 Japan

Abstract

Patterns of fishing ground selection were characterised using STATLANT and CCAMLR fine-scale data. Among the 15 small-scale management units (SSMUs) within Subareas 48.1, 48.2 and 48.3, including the pelagic SSMUs, only one-third were identified as major contributors to the total catch. A recent shift in operational timing towards later months within fishing seasons was observed in Subarea 48.1 (December–February to March–May). However, operational timing has remained relatively constant in Subareas 48.2 (March–May) and 48.3 (June–August). In 25 years of krill operations in Area 48, patterns of SSMU usage have changed. Three different patterns of seasonal SSMU selection were characterised using a cluster analysis. Frequently used SSMUs did not always match the areas of high krill density observed by scientific surveys, and possible reasons for this mismatch are further discussed. A revised format for data submission is suggested in order to accommodate possible developments in fishing techniques.

Résumé

Les tendances de la sélection des lieux de pêche sont établies au moyen des données STATLANT et des données à échelle précise de la CCAMLR. Sur les 15 unités de gestion à petite échelle (SSMU) des sous-zones 48.1, 48.2 et 48.3, SSMU pélagiques comprises, il est apparu qu'un tiers seulement avaient contribué de manière significative à la capture totale. On observe que récemment, dans la sous-zone 48.1, les opérations se sont déroulées plus tard dans la saison de pêche (passant de décembre–février à mars–mai). Toutefois, l'époque des opérations de pêche est restée relativement constante dans les sous-zones 48.2 (mars–mai) et 48.3 (juin–août). Dans les 25 années d'opérations de pêche au krill dans la zone 48, on constate une variation dans l'utilisation des SSMU. En effet, à partir d'une analyse en grappes, on a pu déterminer trois schémas différents de sélection saisonnière des SSMU. Les plus fréquentées ne correspondent pas toujours aux secteurs de densité élevée de krill observés par les campagnes d'évaluation scientifiques. Les raisons possibles de cette divergence sont discutées dans le présent document. Afin de pouvoir tenir compte des nouvelles techniques de pêche, il est suggéré d'adopter un nouveau format de soumission des données.

Резюме

С использованием мелкомасштабных данных STATLANT и АНТКОМа описываются тенденции выбора промысловых участков. Из 15 мелкомасштабных единиц управления (SSMU) в подрайонах 48.1, 48.2 и 48.3, включая пелагические SSMU, только треть можно считать основными источниками общего вылова. В последние годы в Подрайоне 48.1 наблюдался сдвиг во времени проведения операций в пределах промысловых сезонов (с декабря–февраля на март–май). При этом время проведения операций оставалось относительно стабильным в подрайонах 48.2 (март–май) и 48.3 (июнь–август). За 25 лет ведения крилевого промысла в Районе 48 картина использования SSMU изменилась. С помощью кластерного анализа описываются три разных тенденции выбора SSMU по сезонам. Часто используемые SSMU не всегда совпадают с районами, где в ходе научных съемок наблюдается высокая плотность криля; возможные причины этого несовпадения обсуждаются дополнительно. Предлагается пересмотренный формат для представления данных с тем, чтобы учесть возможные изменения в промысловых методах.

Resumen

Se analizaron las pautas de selección de los caladeros de pesca a partir de los datos STATLANT y los datos en escala fina de la CCRVMA. Solamente un tercio de las 15 unidades de ordenación en pequeña escala (UOPE) de las Subáreas 48.1, 48.2 y 48.3 (que incluyen las UOPE pelágicas) fueron identificadas como principales contribuyentes al total de la captura. En la Subárea 48.1, recientemente las operaciones de pesca dentro de la temporada se atrasaron en unos meses, de diciembre–febrero a marzo–mayo. Sin embargo, la época de la pesca ha permanecido relativamente constante en las Subáreas 48.2 (marzo–mayo) y 48.3 (junio–agosto). En los 25 años de pesca de kril en el Área 48, las pautas de utilización de las UOPE han cambiado. Se caracterizaron mediante un análisis de conglomerados tres pautas distintas de selección de las UOPE por temporada. Las UOPE utilizadas con mayor frecuencia no siempre correspondieron con las áreas de mayor densidad de kril observadas en las prospecciones científicas, y las posibles razones de esta incongruencia han sido analizadas más a fondo. Se propone un formato nuevo para la presentación de datos a fin de acomodar el desarrollo de las técnicas pesqueras.

Keywords: small-scale management units, SSMU, CPUE, fine-scale data, CCAMLR

Introduction

In 2004, CCAMLR's Working Group on Ecosystem Monitoring and Management (WG-EMM) agreed to hold a workshop to evaluate candidate management procedures for subdividing the precautionary catch limit for krill among small-scale management units (SSMUs) in Area 48. The workshop will evaluate candidate procedures by quantifying the degree to which they are robust or sensitive to key sources of uncertainty. The concepts developed during the Workshop on Plausible Ecosystem Models (SC-CAMLR, 2005), paying particular attention to the interactions between the krill population, the krill fishery, krill predators and the transport of krill, will form the basis of this evaluation.

When considering options for subdividing catch limits, the behavioural patterns of fishing vessels are one of the most important factors, since if the seasonal behavioural patterns of the fishery are understood, this will allow simulation of various relevant fishing patterns/scenarios for the ecosystem model when evaluating candidate management procedures. The aim of this paper is to characterise trends in fishing patterns across years, seasons and nations.

Materials and Methods

Dataset

STATLANT statistics were obtained from the public domain section of the CCAMLR website, and the fine-scale data were obtained through the CCAMLR Secretariat following the Rules for Access and Use of CCAMLR Data (fine-scale catch and effort data). The STATLANT database contains all reported krill catches at FAO statistical area/subarea resolution. Fine-scale catch and effort data consist of data which are finer than STATLANT statistics, but include data at various levels of resolution depending on the fishing seasons and nations concerned (the current requirement is haul-by-haul data (CCAMLR, 2005), but previously the minimum requirement was 10 n miles x 10 n miles x 10 days or finer, whereas in earlier years it was 30 n miles x 30 n miles x 30 days or finer). Also, fine-scale data coverage was not complete, especially in the earlier days until the mid-1980s (Ramm et al., 2005). Japanese data used in this study were not taken from the CCAMLR fine-scale database (Japanese catches are reported to and held in the CCAMLR database at a resolution of 10 n miles x 10 n miles x 10 days), but are based on the original haul-by-haul data held in the National Research Institute of Far Seas Fisheries (Japan) for a more accurate allocation of catches to each of the SSMUs.

Analysis

Fine-scale catch data consists of either haul-by-haul point data, 10 n miles x 10 n mile grid data or 30 n mile x 30 n mile grid data x 10-day period. All data points were assigned to SSMUs (Figure 1). For the 10 n mile x 10 n mile or 30 n mile x 30 n mile accumulated data, latitude and longitude of the centre location of each grid square was used to assign the data to SSMUs. Fishing seasons were further subdivided into quarterly periods (a: December–February; b: March–May; c: June–August; d: September–November). All the spreadsheet analyses were performed using Microsoft Excel. Cluster analysis was undertaken using the statistical software package S-plus 6.2.

Definitions of terms and abbreviations

A number of abbreviations and specific terms are used in this manuscript. Their definitions are as follows:

SSMUs (Figure 1):

APE: Antarctic Peninsula East
APW: Antarctic Peninsula West
APBSW: Antarctic Peninsula Bransfield Strait West
APBSE: Antarctic Peninsula Bransfield Strait East
APDPW: Antarctic Peninsula Drake Passage West
APDPE: Antarctic Peninsula Drake Passage East
APEI: Antarctic Peninsula Elephant Island
SOSE: South Orkney South East
SOW: South Orkney West
SONE: South Orkney North East
SGW: South Georgia West
SGE: South Georgia East
481PA: Pelagic Area of FAO Subarea 48.1
482PA: Pelagic Area of FAO Subarea 48.2
483PA: Pelagic Area of FAO Subarea 48.3
484PA: Pelagic Area of FAO Subarea 48.4
486PA: Pelagic Area of FAO Subarea 48.6.

Importance of SSMUs: Scaled indices which are calculated as 'Catch within SSMU divided by sum of catch across SSMUs during the given period of interest (e.g. month, fishing season, etc).' In Figure 4 the size of the symbols denotes the relative importance of the SSMU, and in Figures 5(c), 7, 8 and 9, the darker the symbol the more important the SSMU.

Standardised catch: Annual catch within an SSMU divided by total catch within Area 48 during a fishing season. This gives the catch in an SSMU as a proportion of the annual catch in Area 48 as a whole; the size of the symbols in Figures 5(a) and (b) denote the relative size of the catch.

Countries:

ARG: Argentina
CHL: Chile
GBR: United Kingdom
JPN: Japan
KOR: Republic of Korea
POL: Poland
RUS: Russian Federation
SUN: Former Soviet Union
UKR: Ukraine
URY: Uruguay
USA: United States of America
VUT: Vanuatu

Fishing seasons and calendar years: CCAMLR fishing seasons start on 1 December and end on 30 November. For example, the fishing season starting on 1 December 1995 and ending on 30 November 1996 is expressed as 1995/96. If the years are simply expressed as a single year, e.g. 1996, then these refer to calendar years.

Results

Overview of total catch by area and subarea

Figure 2 shows the total catch for each quarterly period since 1980 in Area 48 based on STATLANT data. Subarea 48.1 was consistently used throughout the period. In the earlier days (~1990) the catch was mainly taken during the December–February period, however in the mid-1990s, the March–May period became the main season. In recent years, fishing often continued until the June–August period. Catches in this area have decreased slightly in recent years. In Subarea 48.2, catches were variable across fishing seasons, but fishing was generally more active before 1993. The main season for fishing in this area was March–May. Relatively large catches were reported before 1993 but only occasionally after 1993. Recently, catches from this area have increased. Subarea 48.3 became the main fishing area from 1985 until 1993, but after this period the level of catch reduced to the same level as Subarea 48.1. Recently, the catch in this area has been increasing. The timing of operations in this area for the entire period (mainly June–August) seems unchanged but fishing activities have often lasted until September–November.

Trends in overall catches by SSMU

Figure 3 shows the distribution of catches for each quarterly season since 1980 in each SSMU within Area 48 based on fine-scale data. It should be noted that, as mentioned above, the proportion of fine-scale data coverage before the 1987 fishing season was less than 50%, and therefore may not represent the true pattern.

Subarea 48.1

APDPW, APDPE and APEI were the main SSMUs contributing to the total catch in this subarea (88% of the catch). Within these three SSMUs, the main quarterly periods for fishing in this subarea were December–February and March–May up to 1992, but from 1993 onwards, the fishing season shifted to later in the season, mainly March–May. More recently (1995–2002), fishing continued as late as the June–August period. The use of SSMUs was variable between years. From 1987 to 1991, APEI and APDPE appeared to be the main fishing grounds in this subarea. From 1992 onwards, APDPW had larger catches relative to APEI and APDPE. Catches from APEI have remained low since then. Catches from APDPE increased from 1997 to 2001. From 2003 onwards, contributions of these three main SSMUs were negligible in relation to the overall catch. Interestingly, in 2001/02, some catch was reported from APBSE and APBSW during the June–August period (mid-winter). Another interesting point is that although the pelagic area in Subarea 48.1 has never become a major fishing ground, there seems to be a systematic decrease in catches in this SSMU across time, and few catches have been reported in recent fishing seasons.

Subarea 48.2

SOW is the only SSMU that has significantly contributed to the catch reported from this subarea (70% of the catch). The main quarterly fishing period was March–May, but some catches were also taken in the December–February and June–August periods. This pattern was consistent throughout the entire period with sufficient data coverage. Catch size varied across time. Large catches were reported in 1988, 1990, 1991, 1995, 1999, and 2002 onwards, but in other years, the contributions to the overall catches were minor. Catches reported from the pelagic area were minor except in the earlier days (1989, 1990 and 1992).

Subarea 48.3

SGE is the SSMU that contributed most of the catch reported from this subarea (77% of the catch). The main quarterly fishing period was June–August, but some catches were also reported from the March–May period from the late 1980s to the early 1990s. In most of the fishing seasons, operations continued as late as the September–November period. From 1987 to 1991, consistent catches were reported. This catch level declined in 1992, and only a negligible catch was reported in 1993. From 1994 onwards, catches were consistently reported, but at lower levels compared to the earlier days (with exception of a negligible catch in 1999). Except for 1988, almost no catches were reported from the pelagic area in Subarea 48.3.

Subareas 48.4 and 48.6

Other than occasionally, no regular krill fishing took place within these subareas.

Patterns of fishing ground usage
by the five major krill fishing nations

Figure 4 illustrates the importance of fishing grounds within each quarterly period for each major krill fishing nation.

In the case of Japanese fleets (shown as •), Subarea 48.1 has been the main fishing ground for a long time, but the usage of SSMUs in time and space has changed quite dramatically. Until 1990, the main quarterly fishing season started in the December–February period and extended to the March–May period, however, from 1991 onwards the main operation period shifted to March–May, and from 1996 it even extended as late as the June–August period. Until 1991, APEI and/or APDPE were the two main grounds in Subarea 48.1, but from 1992 onwards, APDPW took precedence as the most constant source of krill catches. In Subarea 48.2, SOW is the main SSMU where fishing took place only and never regularly. The timing of operations within fishing seasons in the earlier days was the December–May period, but more recently fishing has tended to take place later (June–August). The Japanese operation in Subarea 48.3 started in winter 1990 and both SGE and SGW were equally used, but since 1994, the main fishing ground has been SGE. The catch in this SSMU had increased by 1995 and SGE has become the major source of overall catch since then. The principal period of operation of the krill fleets has remained June–August. It is also worthwhile to note that recent catches during the September–November period have also been taken from SGW, which suggests a shift of fishing grounds from east to west as the season progresses.

The SUN fleets seemed to use SGE or SOW as their main fishing ground, and also to some extent the pelagic SSMUs in some seasons. SGE was used mainly during winter and SOW mainly during summer to autumn. Almost no catch was made from Subarea 48.1 except in autumn 1990.

The successors of the SUN, UKR and RUS fleets seemed to have inherited their patterns of fishing ground usage from SUN (SGE and SOW). In later years, UKR occasionally used APEI (1996) and APDPW (2001), but maintained its main fishing grounds in SGE and SOW. UKR also started to use SGW in later years.

The USA is a new entrant into the krill fishery, beginning operations late in the 1999/2000 fishing season. For the first two seasons, it only operated from winter to early spring (June–September). In 2000, it fished in SSMUs in Subareas 48.1, 48.2 and 48.3. In 2001, although it was active during the winter season, it fished only in SSMUs in Subarea 48.1. From the 2001/02 season it again started to fish in SSMUs in Subareas 48.1, 48.2 and 48.3, beginning with the SSMUs in Subarea 48.1 earlier in the season.

Trends in catches in the Japanese krill fishery by SSMU

Japan is the only nation that has continued fishing, maintaining relatively constant catch levels in Area 48 since the krill fishery started, and has been continuously sending krill fleets to the South Atlantic since 1980. This long-term dataset from a single country provides information on baseline trends throughout the entire period. This is why Japanese catch and effort data is so valuable for the analysis of krill fleet behaviour (Kawaguchi et al., 2005).

Although there have been few changes in the operational techniques used by the Japanese krill fishery (Kawaguchi et al., 1997, 1998, 2005), there have been obvious changes in patterns of fishing ground selection over the entire period (Figure 4).

Figure 5 indicates how the distribution of catch and effort in each SSMU and month of operation have changed from the early days in the Japanese krill fishery. Standardised catch and effort basically showed similar patterns (Figures 5a and b). When the importance of each SSMU was examined (Figure 5c), although overall catch was low in the early 1980s, the important SSMUs were actually the pelagic SSMUs in Subareas 48.1 and 48.2. From 1985 onwards, regardless of the amount of catch, the important SSMUs tended to shift southwestwards, from SOW in 1985 to APDPW in 1992. Since then, APEI and APDPE have decreased in importance. This seems to be a consistent pattern for recent years, except for the years with occasional high catches in SOW (1999, 2002). As previously mentioned, as high catches were occasionally reported from SOW, this is certainly an important area, but this pattern did not seem to continue. SGE maintained a high overall catch since 1995; however, when catches were high in SOW the importance of SGE was low. Overall, the history of the Japanese krill fishery in Area 48 could be divided into two sub-periods. The first period is 1980–1989, when no fishing took place in Subarea 48.3, and Subareas 48.1 and 48.2 were both used, including some operations in the pelagic SSMUs. The second period is 1990 onwards, after operations in Subarea 48.3 had begun. The months of operation in the earlier days started in October/November and finished in March/April. Recently, the start of the fishing season has shifted to December/January. From 1990 on, fishing operations were also undertaken in winter and the fishing season lasted until October at the latest.

Grouping of nations based on fishing ground usage

A cluster analysis was performed to group the nations according to their fishing patterns (SSMU selection). As mentioned in the previous paragraph, Japanese catch history was subdivided into two periods (1980–1989 and 1990 onwards). The percentage of the catch from each SSMU was calculated for each nation, based on the total catch reported. Interestingly, the fishing patterns could be subdivided into three main groups, with two stand-alone nations (Figure 6).

The first group (Group A) consisted of SUN, UKR, USA and RUS, which mainly used Subareas 48.2 and 48.3. The second group (Group B) consisted of KOR, POL and JPN (1990 onwards), which mainly used Subareas 48.1 and 48.3. The third group (Group C) consisted of ARG, URY, JPN (1980s) and CHL, which mainly used Subareas 48.1 and 48.2. GBR is a stand-alone nation which only fished in Subarea 48.3 once. VUT is another stand-alone nation which recently entered the krill fishery and whose reported catch was mainly from Subarea 48.3.

Seasonal patterns in fishing ground selection

Figure 7 shows patterns of within-season fishing ground selection for Group A. During the period December to March, the catches are taken from either SOW or the pelagic area of Subarea 48.2, with slightly greater importance in SOW. In April, SOW becomes the most important with a slight increase in catches in SGE. In May, both SOW and SGE become equally important, but the importance of SGE increases in June and remains high until September–October when the fishing season ends. The use of SSMUs in Subarea 48.1 by this group is negligible.

Figure 8 shows the pattern for Group B. From December to May, APDPW is of primary importance for this group, with SGE taking precedence from June until the end of the fishing season, and SGW becoming important in September. Operations in SOW mainly took place from February to

Table 1: Accumulated haul-by-haul catch statistics for the 2000/01 to 2003/04 fishing seasons. GBR – United Kingdom; JPN – Japan; KOR – Republic of Korea; POL – Poland; RUS – Russian Federation; SUN – former Soviet Union; UKR – Ukraine; URY – Uruguay; USA – United States of America; VUT – Vanuatu.

Nationality	Total catch (tonnes)	Number of hauls	Catch per tow (tonnes)
GBR	16.1	8	2.0
JPN	212 431.3	17 597	12.1
KOR	5 912.6	1 218	4.9
POL	22 958.4	2 940	7.8
RUS	775.0	48	16.1
UKR	47 289.2	3 545	13.3
USA	22 436.9	1 459	15.4
VUT	15 530.0	129	120.4

July, but this SSMU has never become the most important area, which suggests that the South Orkney area was basically used as a transit area for vessels moving from Subareas 48.1 to 48.3.

Figure 9 shows the pattern for Group C. This group basically operated only from summer to early autumn (December–April). The main fishing grounds were APEI and APDPE. APDPW has never been of primary importance for this group. SOW was also mainly used in February and March, but this again did not become the SSMU of importance.

Trends in CPUE

Figure 10 shows quarterly seasonal trends in towing time per tow (Figure 10a) and CPUE (Figure 10b) for different nations in five major SSMUs. JPN consistently employed short tows (0.5–1.5 h) with high CPUEs compared to other nations throughout the five SSMUs. SUN employed long tows (~3 h) wherever it operated and the CPUEs were consistently low. After SUN ceased operations, its successors UKR and RUS also tended to operate using long tows. Towing times per tow were highly variable for these two nations especially for the earlier fishing seasons (1–6 h/tow). CPUEs for these two countries were generally low until the late 1990s, but then showed a general increase from the 2000/01 season onwards, with increasing variability. Until the 1990/91 fishing season, POL tended to show similar patterns in towing time per tow and CPUEs to SUN. From the 1991/92 season onwards, POL started to consistently employ shorter tows throughout the area (1–2 h), slightly longer on average compared to JPN. Accordingly, Polish CPUE increased from an average of 2.2 tonnes/h (until 1990/91) to 3.7 tonnes/h (from 1991/92 onwards). KOR did not fish every season but whenever it did, it tended to show similar towing times as JPN, but CPUEs were at the lower end of the Japanese CPUEs.

Another point worth noting is that there seemed to be a period during which CPUE was low throughout the five SSMUs (1995/96–1996/97 fishing seasons). Also there were some fishing seasons when some of the nations recorded significantly longer tows in most of the five major SSMUs but not APDPW (1991/92, 1995/96, 2001/02).

Recent catch-per-tow statistics

The figures in Table 1 are calculated using the fine-scale data submitted to the CCAMLR Secretariat during the 2000/01–2003/04 fishing seasons as well as Japanese haul-by-haul data. Catch per tow for GBR, JPN, KOR, POL, RUS, UKR and USA ranged from 2.0 to 15.4 tonnes, which falls with our general understanding of the catch pattern for the krill fishery. Interestingly, VUT, which newly entered the krill fishery in the 2003/04 season, showed an extremely high catch per tow (120.4 tonnes) but this is likely to reflect the changed technology that it had applied (SC-CAMLR, 2005).

Discussion and conclusions

The major krill fishing grounds and krill distribution

The analysis revealed an interesting pattern for the overall catch subdivided among the SSMUs. Firstly, among the 15 SSMUs within Subareas 48.1, 48.2 and 48.3, including the pelagic areas, only one-third of the SSMUs (APDPW, APDPE, APEI, SOW and SGE) contributed significantly (78%) to the total catch. The SSMUs generally used match reasonably with observed areas of locally high krill density (e.g. Hewitt et al., 2004a).

It is possible that fishing fleets tend to operate in the areas where they know through their experience and external information that reasonable krill densities are consistently formed. Hewitt et al. (2004b) examined time-series distribution patterns of krill in the South Shetland Islands, and interestingly indicated three areas of consistently high density, one near the eastern end of Elephant Island, one mid-way between Elephant Island and King George Island, and one near Cape Shirreff. Off Cape Shirreff is obviously one of the major fishing grounds; however, recent catch data show that neither the Elephant Island area, nor the point midway between Elephant Island and King George Island are major fishing grounds.

The krill fishery is of course an economic activity which can only continue so long as it makes an overall profit (Kawaguchi et al., 2005). Factors affecting krill fishing operations include operational risks such as possible physical forces (sea-ice, weather etc.), biological factors such as variation in krill distribution and abundance, krill condition and the influence of market forces (Butterworth, 1988a, 1988b; Kawaguchi et al., 2004, 2005; Litvinov et al., 2003), so it can be seen that fishery operations are not solely dictated by krill density distributions.

Another important point to be raised is the mismatch between the timing of scientific surveys and the principal fishing season (Kawaguchi et al., 2005). As demonstrated (Figures 3 to 5), the timing of the highest levels of fishing effort has recently shifted from summer operations in the 1980s to autumn and winter from the 1990s onwards. On the other hand, most of the information on krill distribution and density from scientific acoustic surveys relates to the summer periods, and evidence from a number of repeated surveys in the same area indicates that there are considerable seasonal changes in krill distribution and abundance (e.g. Hewitt et al., 2004b). In order to relate fleet behaviours to scientifically measured krill distribution and abundance it will be necessary to obtain information on changing patterns throughout the fishing season.

Recent evidence clearly suggests that krill distribution patterns differ between seasons, as indicated by differences in onshore/offshore distribution (Siegel et al., 1997; Lascara et al., 1999), depth distribution and seasonal changes in vertical migration in time and space (e.g. Kawaguchi et al., 1986; Taki et al., 2005; Jackowski, 2002). It is recommended that, as a priority, krill biomass and distribution surveys be conducted later in the season so that scientific information can be gathered during the period during which the major fishing operations take place. It is also important to increase seasonal coverage of CCAMLR scientific observers on krill fishing vessels so that information can be obtained throughout the fishing season.

Fishing grounds and physical conditions

Direct interaction with sea-ice

The often-quoted example of the behaviour of the krill fishing fleet is that the 'krill fleet operation follows southwards the retreating ice-edge bloom and proceeds northwards as ice forms in the autumn' (Everson and Goss, 1991). The overall pattern of total catch from each SSMU generally supports this observation (Figure 3), with SSMUs in the seasonal ice zone (Subareas 48.1 and 48.2) mainly being used during the summer–autumn period and the year-round ice-free zone (Subarea 48.3) being used principally during the winter–spring period when the other areas are not available due to ice cover. Interestingly, operations occurred in the Bransfield Strait SSMUs (APBSE and APBSW) during the winters of 1997/98, 1999/2000 and 2000/01. Usually, these SSMUs are covered by ice during winter (Figure 11a); however, for these particular years, the Bransfield Strait was ice-free during the entire winter (Figure 11b). This suggests that the fishery does try to operate close to the ice edge and moves out when the area becomes inaccessible. Although this supports the general concept suggested by Everson and Goss (1991), there are some exceptions, since there are certain seasons when the South Shetland Islands were ice-free during winter with no fishing operations. Also, if the fishing operations of individual nations during summer are examined separately, some nations (e.g. JPN) fully utilise Subarea 48.1, whereas other nations (UKR, RUS, USA) mainly use Subarea 48.2 and not 48.1 (Figure 5). It is therefore more reasonable to say that although sea-ice conditions are a major factor restricting seasonal access to various fishing grounds, the choice of fishing ground at any given time seems to be the result of many additional factor, including operational reasons.

Physical environment and krill distribution

The South Georgia area (Subarea 48.3) is known to be an area in which krill abundance can be highly variable (e.g. Priddle et al., 1988; Heywood et al., 1985). CPUE indices derived from the SUN fishery during 1977–1992 show correlations with ice, ocean and atmospheric indices, with water temperature exhibiting the most consistent correlation, which suggests that krill abundance is strongly influenced by the oceanographic regime of the Scotia Sea (Fedoulov et al., 1996). The Japanese krill fishery in Subarea 48.3 also seems to be operating at a critical level which is just enough to make a profit, and therefore daily production reduces when krill availability is low (Kawaguchi et al., 2005). These studies capture well the characteristics of the South Georgia area as a fishing ground where krill abundance is variable and fishing takes place only when krill aggregations are present (Litvinov et al., 2003). However, since this fishing ground is ice-free during the winter season, and other areas are generally ice-covered, any krill fishing activities in winter are forced to operate in this area (Figure 4).

Krill recruitment and abundance using scientific net-haul data in the South Shetland Islands area was linked to winter sea-ice conditions (Siegel and Loeb, 1995; Loeb et al., 1997). More recently an eight-year cycle of acoustically estimated krill abundance variability was suggested by Hewitt et al. (2003), and an 80% decline in krill abundance in the southwest Atlantic since the late 1970s was suggested and linked to a decrease in recent winter sea-ice extent (Atkinson et al., 2004). However, CPUE indices in this area generally do not reflect these apparent trends. Possible reasons for this mismatch are thought to be: (i) a spatio–temporal mismatch between scientific survey grids and fishing grounds, and (ii) the possibility that the high variability in krill availability in this area masks any underlying changes. Despite these differences, CPUEs are more highly variable in some years than in others and this must reflect the status of certain aspects of krill distribution which have affected fishing operations.

Preferences in fishing ground selection

Seasonal patterns in Japanese fishing operations in this study clearly show a consistent preference for fishing around the South Shetland Islands, especially in APDPW during the ice-free season. Until 1990, JPN operated from summer to autumn, mainly in the South Shetland Islands area. Its winter operation began in the 1990/91 season in the South Georgia area, when the South Shetland and the South Orkney Islands areas were covered in ice. Interestingly, although this was not evident from the analysis of fine-scale data, from FAO STATLANT statistics it is apparent that SUN fleets mainly operated in Subarea 48.1 (around the South Shetland Islands) in the early 1980s. The principal reason given for the SUN fleets having ceased operations in this area was a decline in krill density (Litvinov et al., 2003), and since then their main fishing ground shifted to Subareas 48.2 and 48.3.

The cluster analysis using fine-scale data revealed that there are several patterns of fishing ground selection which do not seem to be due to krill distribution or ice condition, but appear most likely to be dictated by operational requirements (national policy, economic circumstances etc.) (Litvinov et al., 2003) or pre-determined decision rules characteristic of each nation based on experience (Figures 6 to 9). Since these decisions are driven by factors other than krill distribution, this could in some way have the effect of diluting fishing effort and may to some extent contribute to avoiding a concentration of fishing effort within a small location. However, on the other hand, this relatively fixed fishing pattern may lead to an over-exploitation of local krill populations in years when local krill density is too low to support the demand of predators in the area.

Why do some nations prefer fishing around the South Shetland Islands and others prefer the South Orkney Islands? Although UKR inherited its operation pattern from SUN, it recently also investigated fishing grounds in the South Shetland Islands, yet overall, it still prefers the South Orkney area. The USA, which was grouped in the same fishing ground selection pattern (Group B of Figure 6), actually started operating in the South Shetland Island areas when it first entered the krill fishery, but after a few years of operation, seemed to have chosen South Orkney and South Georgia as its main fishing grounds. On the other hand, JPN and KOR prefer South Shetland over South Orkney. POL initially used South Orkney as its chief summer fishing ground until the early 1990s, when it changed its principal ground to the South Shetland Islands (Group A of Figure 6).

Interestingly, Group A nations tend to employ longer tows (variable in length in recent years) with low CPUEs, while Group B nations generally employ short tows with high CPUEs. Although it must be accepted that the decision 'where to operate' involves the consideration of many issues other than natural factors (Litvinov et al., 2003), there may still be some reasons due to krill distribution characteristics as to why the two different towing strategies resulted in preferences for the different areas. For example, aggregation characteristics such as size, density and location (area of aggregation in relation to topography and coastline) in the two areas may suit different types of tows (SC-CAMLR, 2005). Differences in krill size and maturity north of the South Shetland Islands show a clear relationship to bottom topography (e.g. Ichii et al., 1998), and also locations of green krill and salp by-catch are relatively easy to predict in this area (Kawaguchi et al., 1998). The use of short tows indicates that the fishing operation is concerned with krill quality (freshness and appearance including colour, size, salp by-catch) as a priority over quantity. If that is the case, it may then be advantageous for vessels to operate in an area in which these factors are more easily predicted, such as north of the South Shetland Islands. On the other hand, fishing strategies using long tows, as represented by SUN operations, generally require high krill abundance over wider areas (e.g. Kasatkina and Ivanova, 2003). However, it is beyond the capacity of this analysis using aggregated fine-scale data to examine the relationship of these operational patterns directly to krill distribution and abundance patterns. It is therefore necessary to collect further detailed information regarding fishing operations, especially regarding skippers' decisions under various situations on the fishing grounds, in order to correctly interpret this observation. Effective use of the CCAMLR observer program, which includes observations of vessel behaviour, will greatly enhance our understanding of vessel behaviour and hence contribute to effective krill fishery management.

Another important factor which may have affected operating strategies is the changing size of fishing fleets. In earlier days, the fleets of major fishing nations (USSR, JPN) used a larger number of vessels (>5) (Kawaguchi et al., 1997; Litvinov et al., 2003) and vessels communicated intensively with each other and used this information to maximise the catch. However, more recently, most krill fishing nations are operating single vessels, a form of operation that requires far more effort to search for profitable krill aggregations (Kawaguchi et al., 2005), and this is likely to affect the pattern of fishing strategies or selection of fishing grounds.

New fishing methods

Finally, there are concerns about the introduction of new fishing techniques which may well change fishing patterns, time allocation, and the types of krill swarms targeted. Such new techniques may well require the collection of additional catch statistics to gain a better understanding of fishing activities and vessel behaviour. For example, the new pumping method employed recently by the vessel from VUT, which continuously pumps up krill from depth, allows a single tow to extend for more than 20 days, making catch per tow is extremely high (Table 1). The average catch reported (120.4 tonnes per tow) would be impossible to land on the deck in one shot using a traditional midwater trawl operation. Therefore it is critical that the data submission format be revised to adequately accommodate the fishing characteristics of these newly introduced methods by the new entrants to the krill fishery. The data submission requirement also highlights the need for widespread deployment of scientific observers to enable the characteristics of and nature of this operation to be well understood and so that they can be compared to more traditional methods (SC-CAMLR, 2005).

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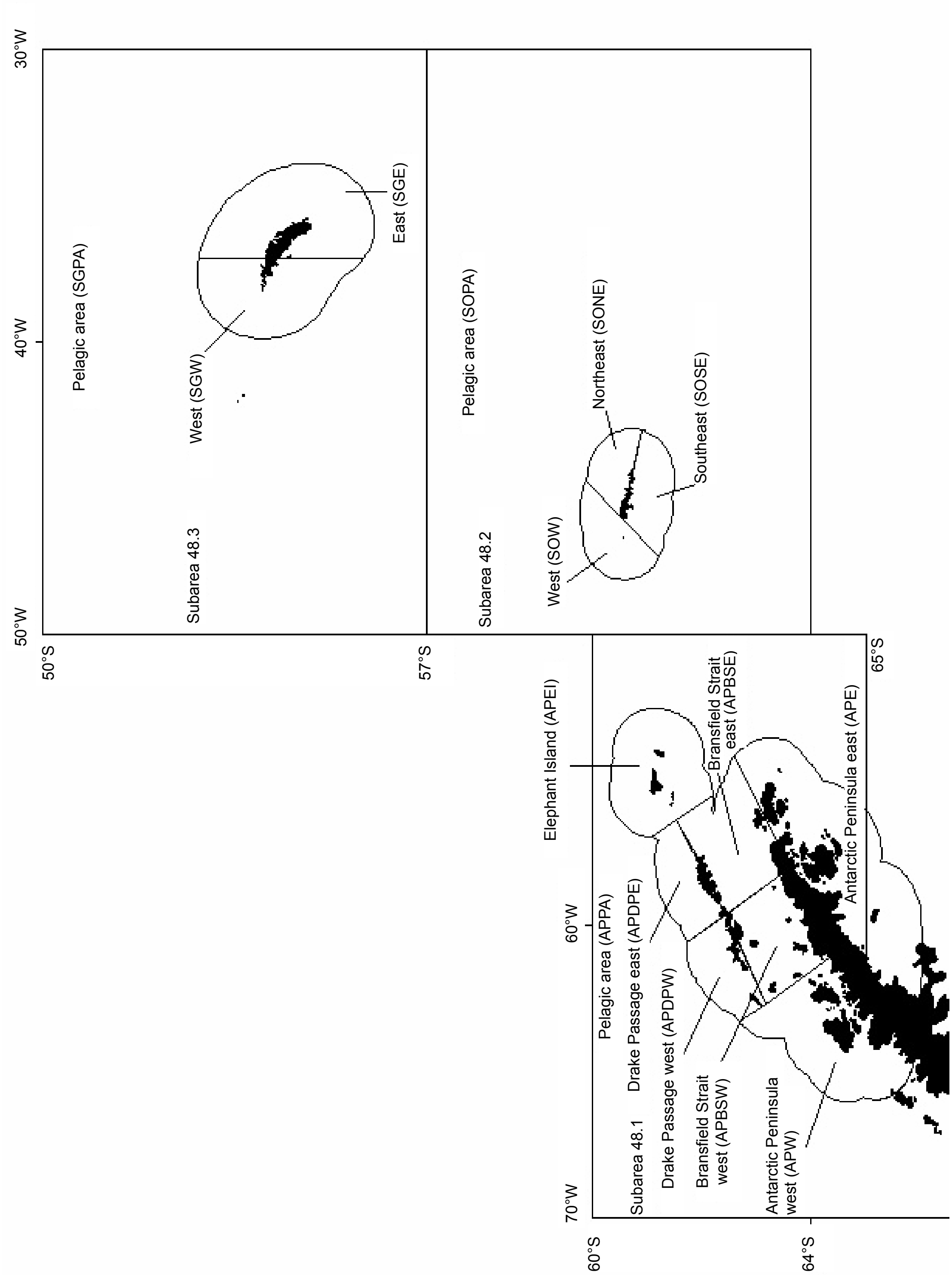


Figure 1: SSMUs in the FAO Statistical Subareas 48.1, 48.2 and 48.3.

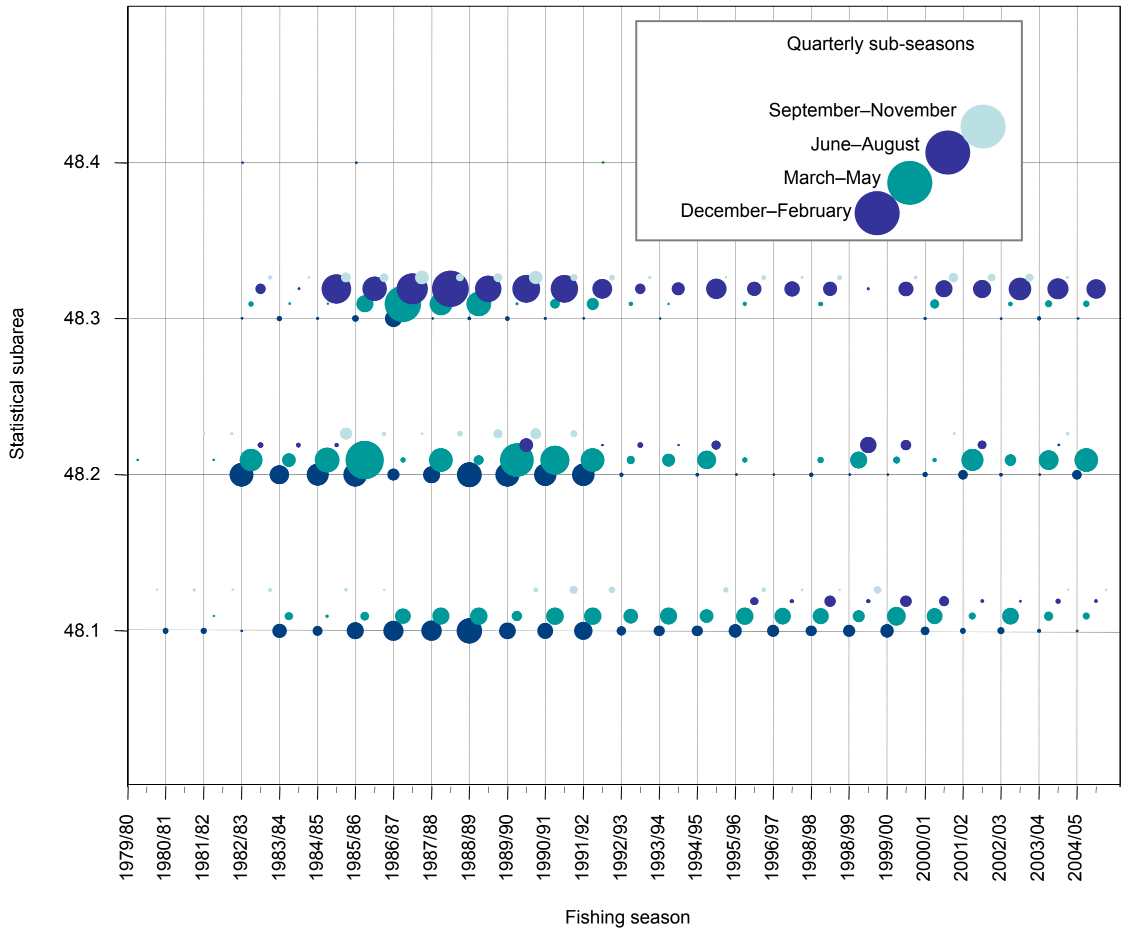


Figure 2: Use of fishing grounds (FAO subareas) across fishing seasons and sub-seasons (quarterly periods) based on the complete STATLANT statistics. Size of the symbol: quantity of catch. Each sub-season has been expressed in different grey tones and offset for clarity (see illustration). Lower left corner of each graticule corresponds to the austral summer of a fishing season.

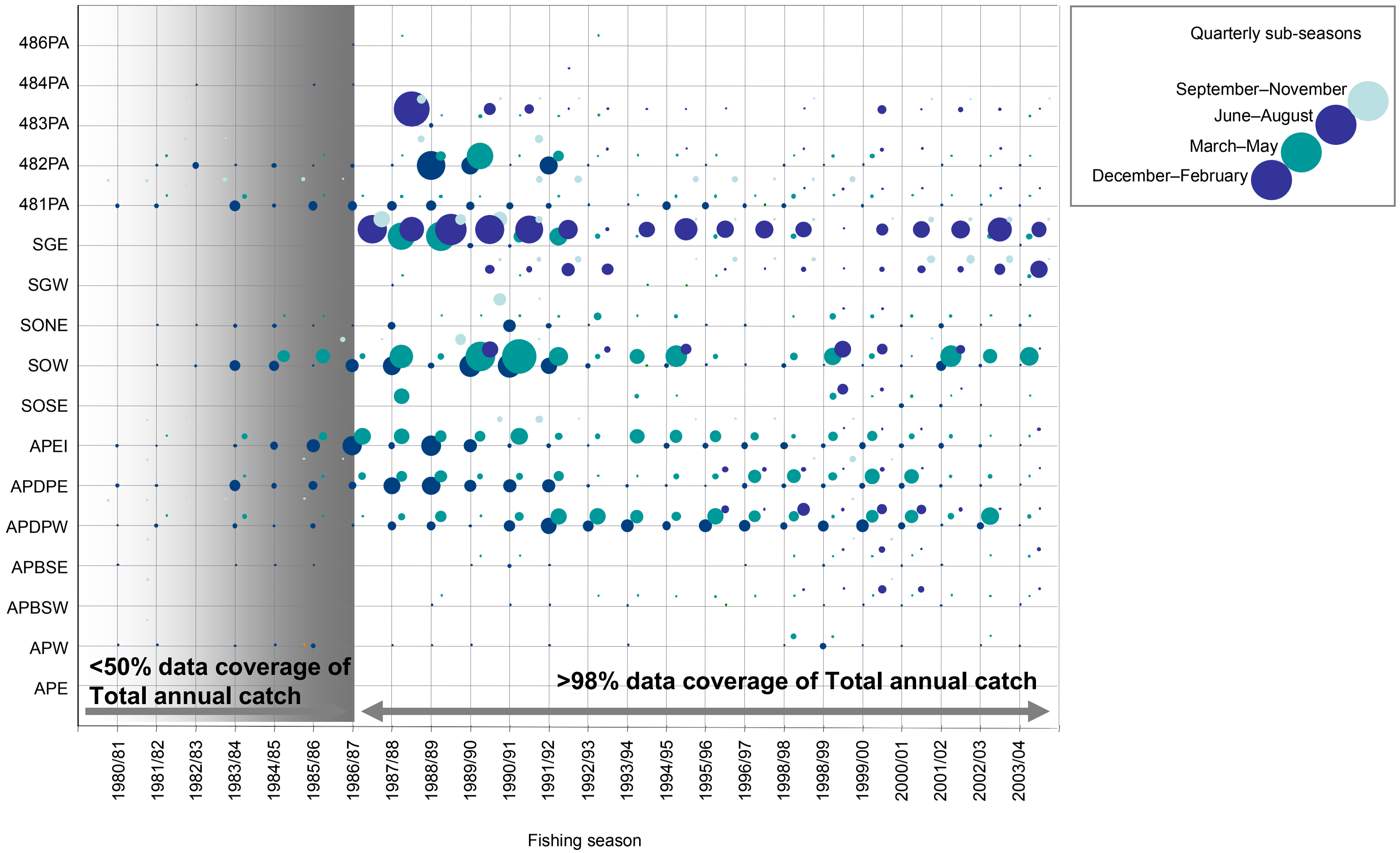


Figure 3: Use of fishing grounds (SSMUs) across fishing seasons and sub-seasons based on the entire CCAMLR fine-scale data up to the end of the 2003/04 fishing season. Size of circles: total catch during each period. Each sub-season has been expressed in different grey tones and offset for clarity (see illustration).

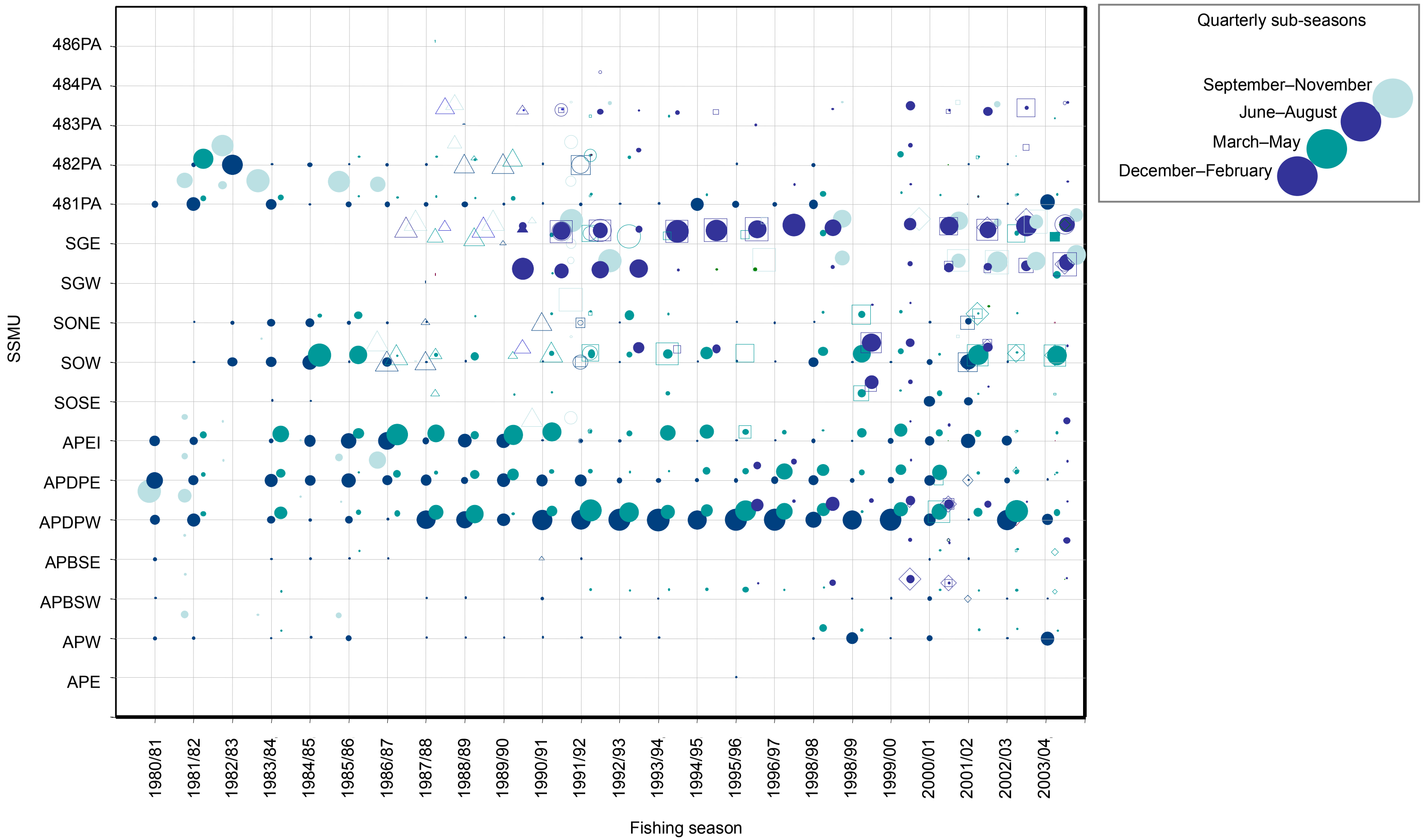


Figure 4: Relative importance of fishing grounds (SSMUs) for five major fishing nations (Japan, former Soviet Union, Russia, Ukraine and USA) across fishing seasons and sub-seasons based on the complete CCAMLR fine-scale data up to the end of the 2003/04 fishing season. Different symbols are used for different Flag States. Size of symbols: relative catch within a quarterly fishing season for each of the Flag States. ● – Japan, △ – former Soviet Union, ○ – Russia, □ – Ukraine, ◇ – USA. Each sub-season has been expressed in different grey tones and offset for clarity (see the illustrative example). Lower left corner of each graticule corresponds to the austral summer of a fishing season.

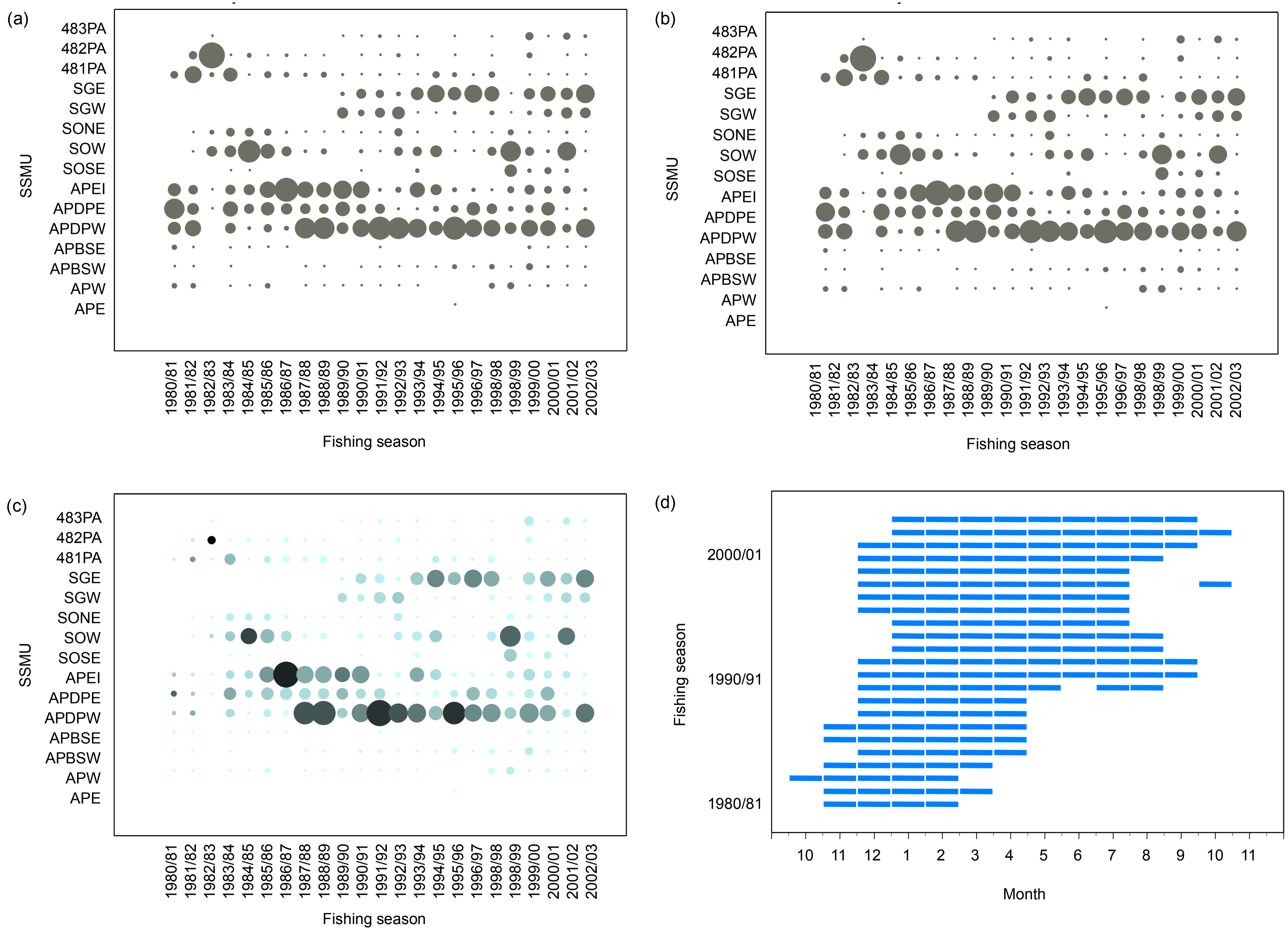


Figure 5: Trends in Japanese krill fishing operations. Year-to-year succession of (a) standardised catch and (b) effort across SSMUs; (c) changes in important SSMUs across fishing seasons; (d) chronological sequence of fishing season periods. Size of symbol: total catch; darkness of symbol: catch standardised across SSMUs within each fishing season. The darker the symbol, the more important the SSMU.

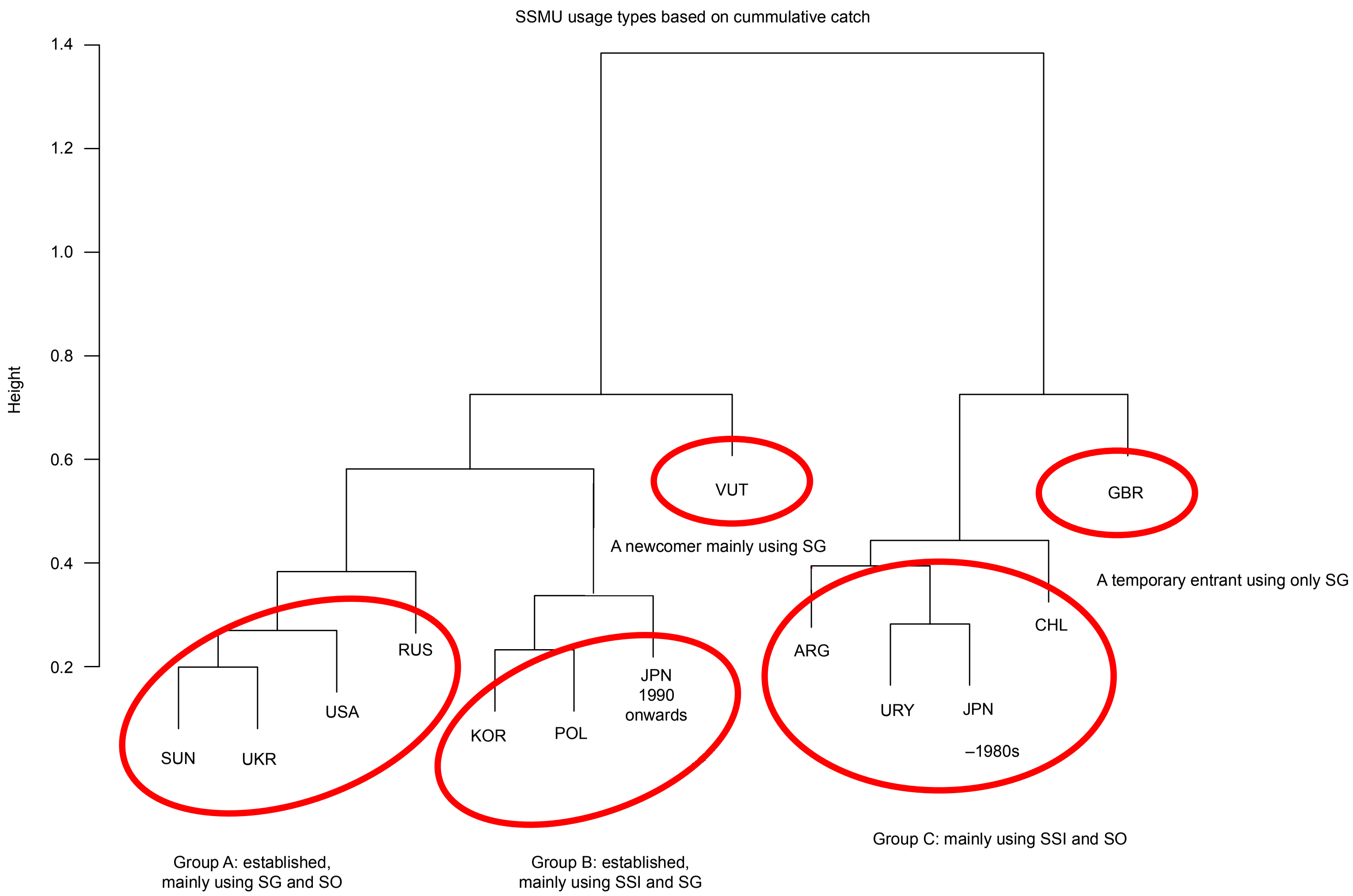


Figure 6: Tree diagram of the result of a cluster analysis undertaken showing the use of SSMUs by each nation.

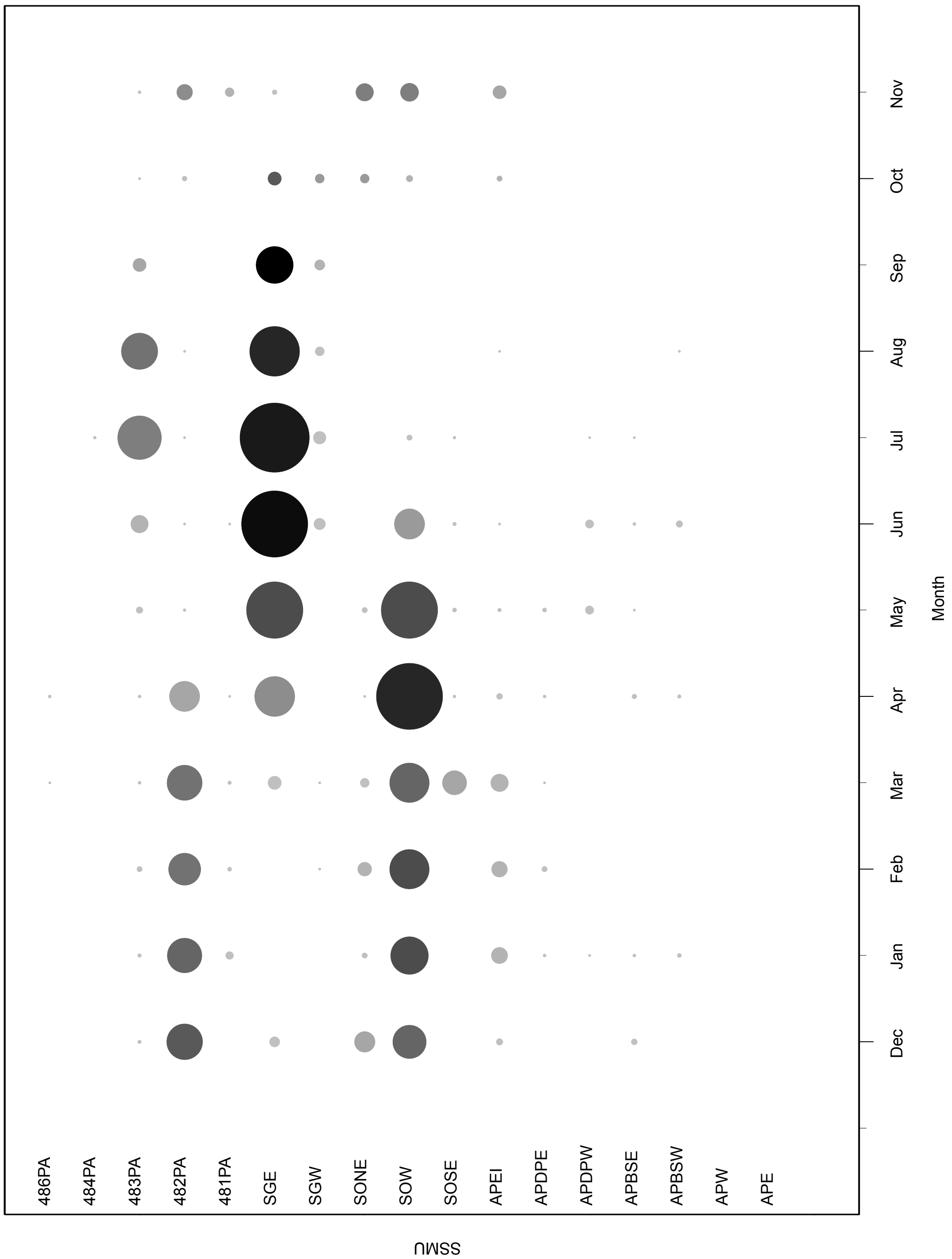


Figure 7: Monthly changes in catches and importance of each SSMU for Group A nations. Size of symbol: total catch; darkness of symbol: catch standardised across SSMUs within each month. The darker the symbol, the more important the SSMU.

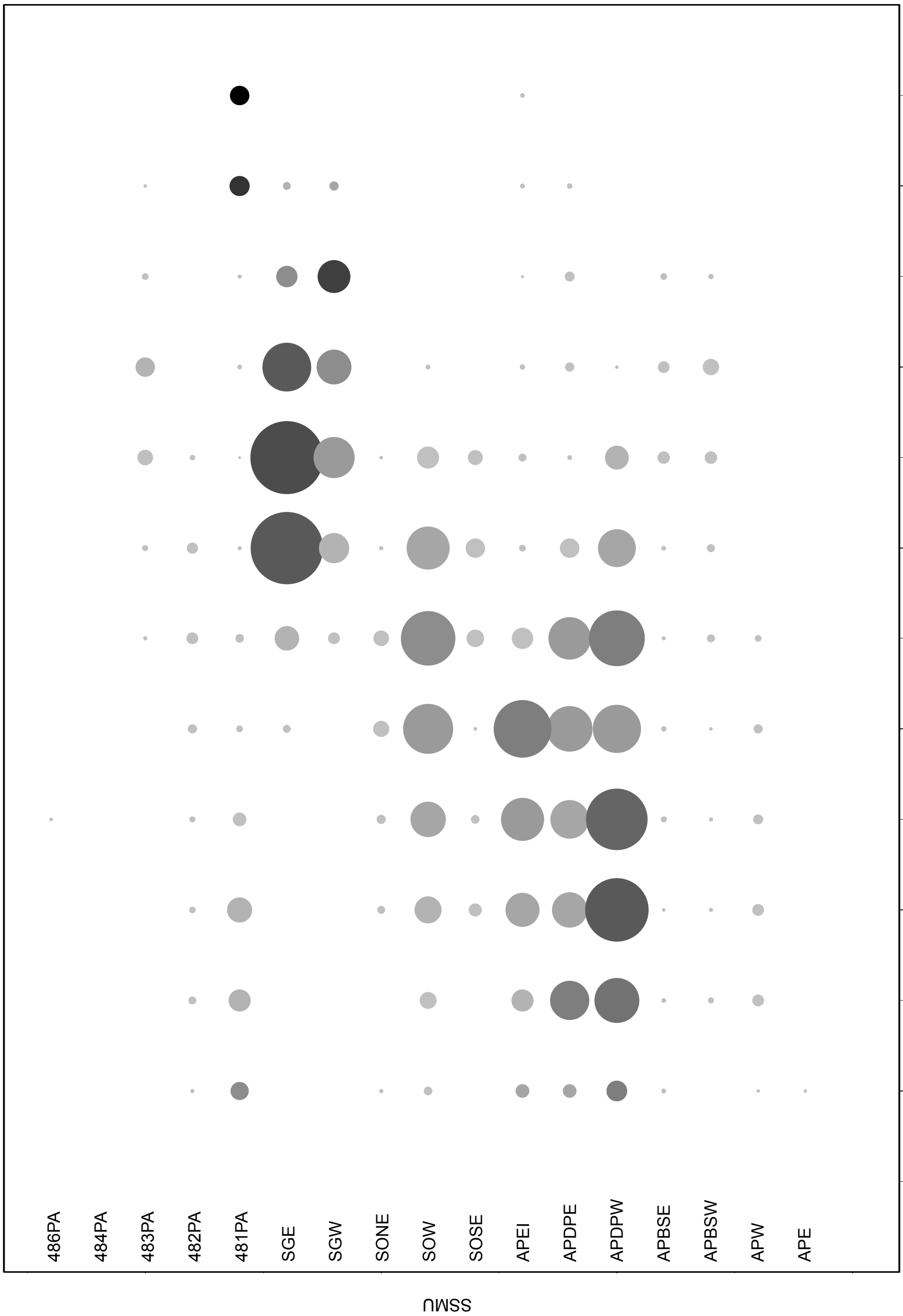


Figure 8: Monthly changes in catches and importance of each SSMU for Group B nations. Symbols: see Figure 7.

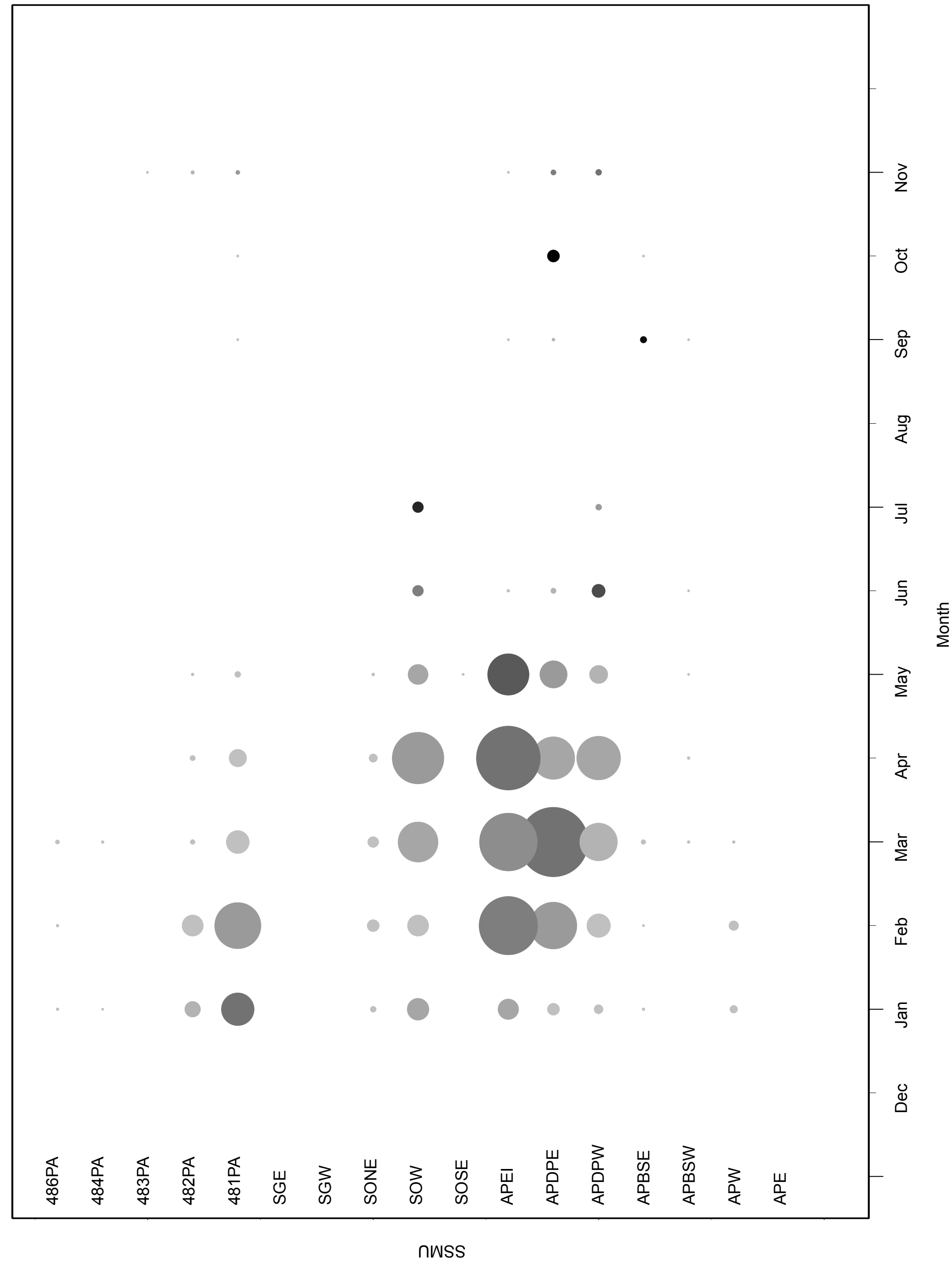
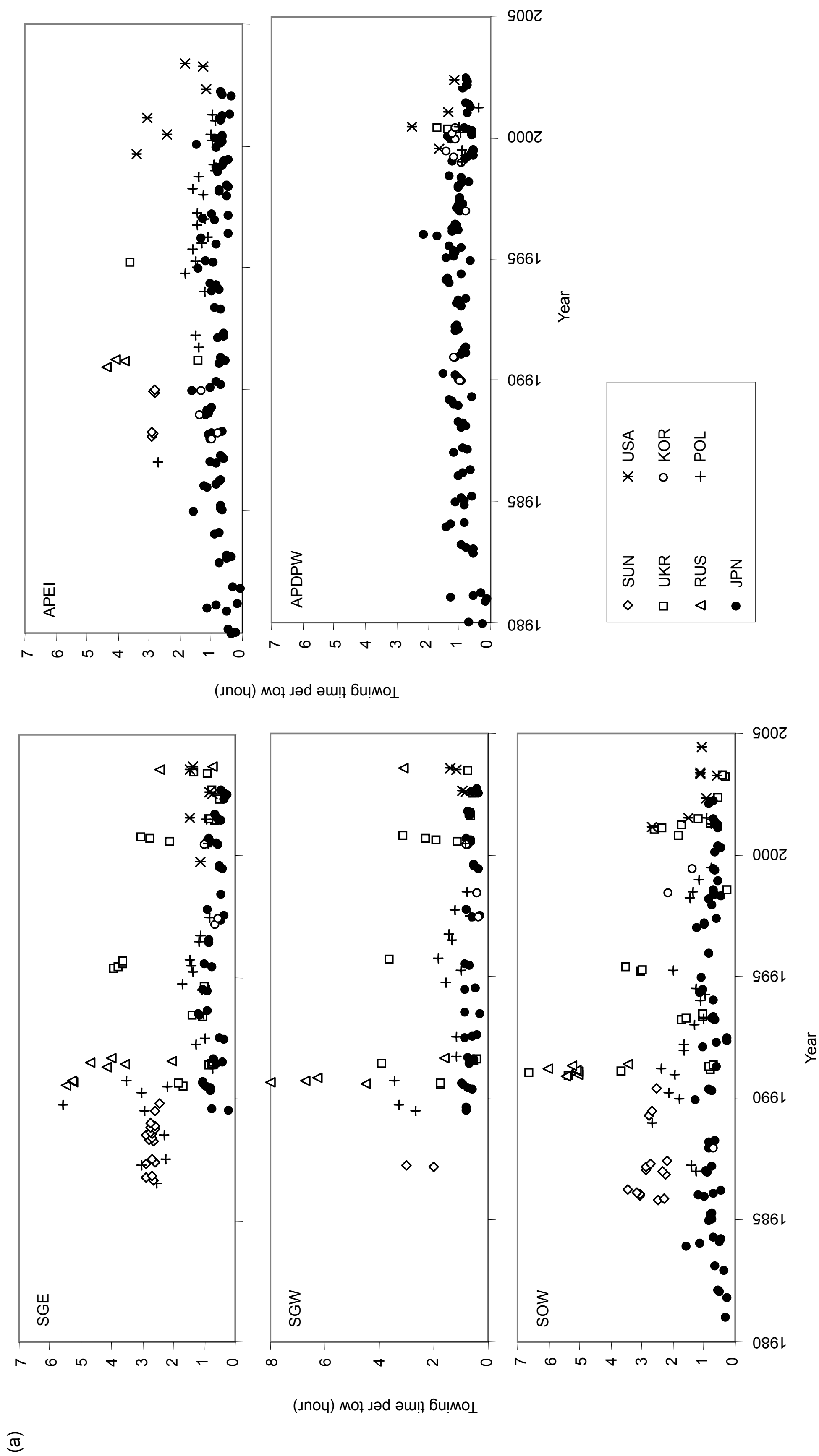


Figure 9: Monthly changes in catches and importance of each SSMU for Group C nations. Symbols: see Figure 7.


(a)
SGE
SGW
SOW
APEI
APDPW
Towing time per tow (hour)
Year
SUN
UKR
RUS
JPN
USA
KOR
POL

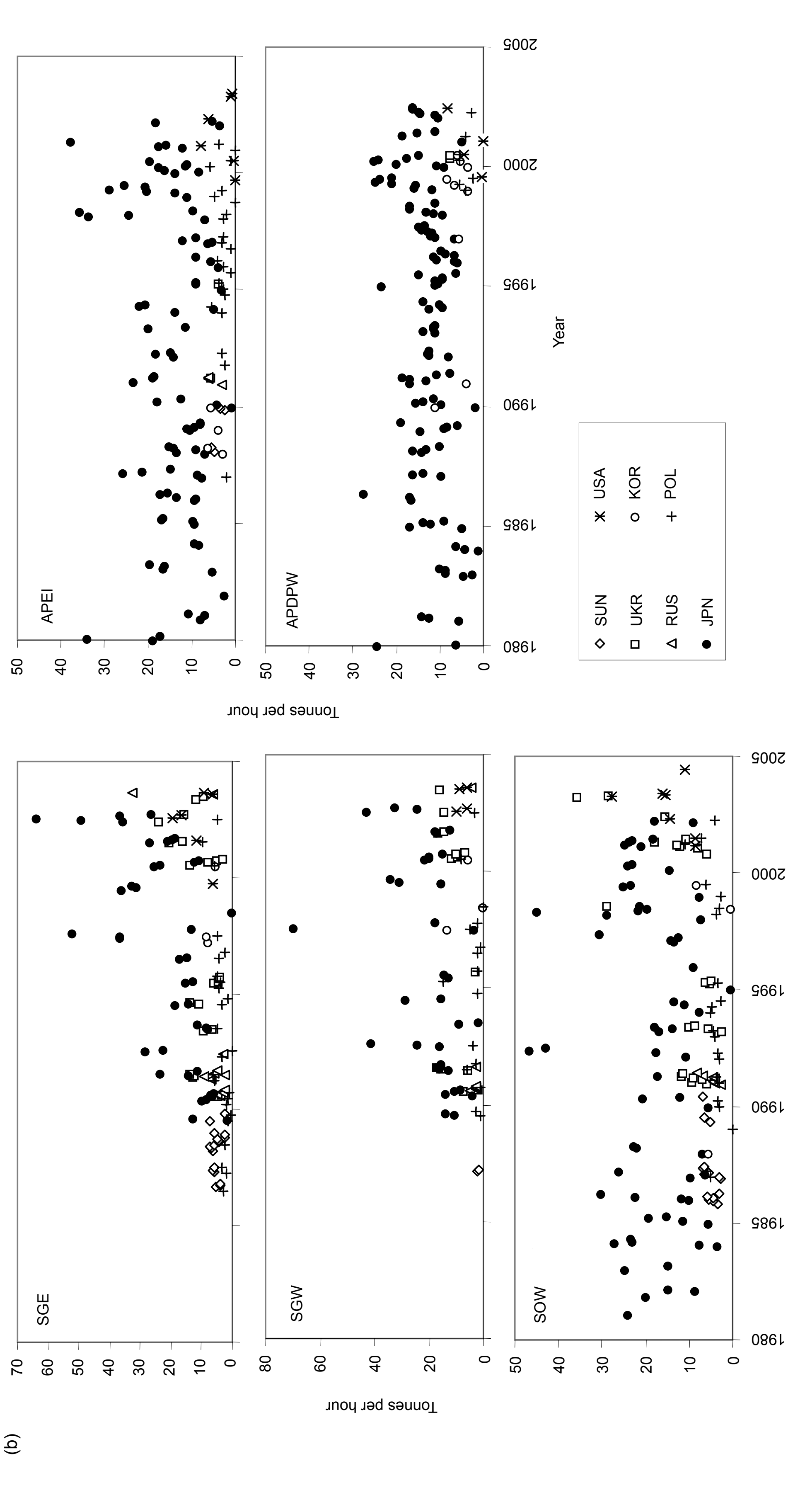
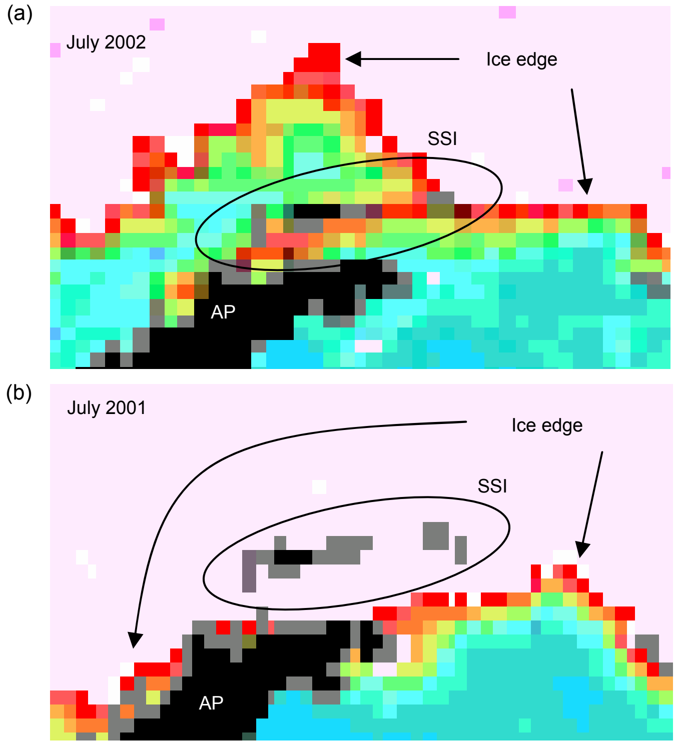


Figure 10: (a) Towing duration (hours/tow) and (b) CPUEs (tonnes/hour) for each quarterly fishing season in the five major SSMUs by the seven major fishing nations.



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