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Management of the Falkland Islands Multispecies Ray Fishery: Addressing Sustainability and Diversity

(Elasmobranch Fisheries – Oral)

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Abstract

A multispecies commercial rajid fishery has been managed in Falkland Islands' waters since 1987. In the absence of detailed biological knowledge and catch-at-age data, management policies currently consider a single assemblage rather than individual species. Simple production models with aggregated catch and effort data are used to estimate sustainable levels of exploitation. As a whole the assemblage appears to have been surprisingly robust to fluctuations in fishing pressure, probably because fishing effort has been regulated within conservative limits.

This paper presents updated production models and examines biological data collected as part of an ongoing observer programme, and during recent research surveys, to examine impacts on individual species in the context of strategies for sustainable management of the multispecies complex.

Introduction

Rajid catches around the Falkland Islands have been recorded since the establishment of the Falkland Islands Interim Conservation and Management Zone (FICZ) in 1987 (Fig. 1). Catches during the 1980s were taken primarily as a part of a general mixed groundfish fishery by Spanish vessels and were less than 1,500 tons annually. However, in 1989 a Korean fleet entered the fishery, specifically targeting rajids, and by 1991 annual catches had risen to over 7,000 tons (Fig. 2). Catches peaked in 1993 at 8,523 tons (Falkland Islands Government, 2002).

Prior to 1993 there had been no specific management for rays. In the face of this rapidly developing directed skate and ray fishery management controls, in the form of specific licences, were first introduced in August 1994. The rajid catch declined following this move primarily in response to the reduction in directed effort. However, it became apparent that there were two distinct rajid fishery areas in the Falklands: a small area to the south of the Islands and a more extensive northern area, in particular the slope areas from 200–300 m depths. These both contained multispecies complexes but were apparently distinct from each other with differing stock dynamics and detailed species make-up (Agnew *et al*., 2000). Stock assessments undertaken in 1995 detected a continuing decline in the CPUE from the stock situated to the south of the Islands due, in particular, to declining abundance of *Bathyraja griseocauda*. To protect this area directed fishing for rays was prohibited south of 52^{o}S from 1996 onwards (Agnew *et al*., 1999). The directed rajid trawl fishery is therefore currently restricted to waters north of the Islands.

Most of the catch of rays in the Falkland Islands comes from the Falklands Interim Conservation and Management Zone (FICZ, see Fig. 1). However, in December 1990 the Falklands Outer Conservation Zone (FOCZ) was established extending to 200 nm from coastal baselines (Falkland Islands Government, 1997) (Fig. 1). Most of this area is too deep for conventional trawling but there is a small amount of licensed longlining targeting patagonian toothfish (*Dissostichus eleginoides*) and a small by-catch of rajids results.

There are two seasons to the Falkland Islands fishing year the first running from January to June and the second from July to December. Most of the rajid trawl fishery has taken place in the second season when the primarily Korean fleet targets rays and finfish to the north of the Islands. According to Korean fishermen the longer nosed *Raja flavirostris* and *Bathyraja scaphiops*, refered to in Korean as 'Hongu', have a better taste and command a better price than the other rajids known as 'Kaori'. However, the mixed nature of the rajid assemblage over the shelf prevents single species targeting and as a result catches in this fishery are always of mixed species. More than twenty different rajid species have been recorded from catches around the Islands and the dominant species in the commercial fishery are listed in Table 1.

The Falkland Islands Government has the long-term maintenance of sustainable fisheries as its primary fisheries policy aim. This, of course, includes the rajid fishery. Stock assessment and licensing levels to date have necessarily treated the multispecies complex as a single unit. However, data from Fisheries Observers and research cruises are being gathered with the long-term aim of understanding the biology, ecology and effect of fishing on individual species. In this paper we examine the current status of the stock as a single multispecies assemblage. We investigate whether this approach is potentially masking local declines in abundance, and describe aspects of the distribution and dynamics of particular rajid species that will influence the impact of the fishery on individual species. This highlights the question of whether management approaches must address the conservation of individual species, and overall biodiversity, in addition to long term sustainability of the multispecies fishery. We restrict our attention to data from the northern ray fishery that is the target of the licensed ray fleet.

Materials and Methods

Fishery data

Two sources of data are available from the commercial fishery. Each licensed vessel reports daily catch and fishing time together with position at midday and midnight on a 0.25° latitude by 0.5° longitude grid. However, only total daily rajid catch is reported with no separation by species. Fisheries Observers are placed on a subset of licensed vessels where they monitor two trawls per day recording catch by species and carrying out random sampling to estimate size (disk width and total length) distributions, sex ratios, and the relationship between size and weight. In the licensed ray fleet the need to keep animals intact (the market requires whole, frozen animals) limits the extent to which ray maturity can be assessed. Only males are classified, using a simplified three-stage maturity scale (Table 2). Maturity stages, of both males and females, can be studied more extensively in rajid by-catch from other fleets, but this data is not considered here.

Stock assessment

Assessments of the skate and ray stock are currently restricted to simple biomass dynamic models. Agnew *et al.* (2000) fitted constant recruitment and Schaefer production models to the total catch (both directed and by-catch) and CPUE data from the licensed fishery operating within four geographic areas around the Falkland Islands. These analyses were performed using the catch and effort data analysis (CEDA) software developed by the Marine Resources Assessment Group (Holden *et al.*, 1995) and a series of *ad hoc* spreadsheets that provided greater flexibility. Overall the goodness-of-fit (R^2) was higher for the Schaefer model than for the constant recruitment model although confidence limits for all parameters were quite wide and for B_0 were skewed. Maximum likelihood methods suggested that there are two distinct rajid stock units, one to the north (Agnew *et al.*'s areas 1 and 2) and one to the south. For comparison with the updated assessment, Agnew *et al.*'s fitted parameters for the Schaefer model for areas 1 and 2 (see Table 6 in Agnew *et al.*, 2000) have been used to construct estimates of annual biomass (B_t) up to and including 1999.

This assessment has been updated using the Schaefer production model (with a 2-year time lag in biomass) within CEDA and a total catch and a tuning series derived from a subset of licensed catch and effort data extended to the end of 2001 (Table 3). Since 1996 the northern skate and ray stock has been considered to lie in the region north of 52° latitude, which to a large extent encompasses both areas 1 and 2 derived by Agnew *et al*. (2000). The tuning series was calculated using mean daily CPUEs selected from Korean vessels in two vessel classes (3 and 4) which were previously identified as the two largest groups with similar standardised CPUE values (see Table 3 in Agnew *et al*. 2000). To ensure that vessels were specifically targeting rays tuning data were restricted to vessels that had a daily rajid catch exceeding 25% by weight of its total catch, north of 52° latitude.

The parameters obtained from this new assessment were used to construct estimates of annual biomass (B_t) up to and including 2001.

Local CPUE trends

The current assessment model for the ray assemblage has no spatial component with the northern ray fishery. A potential concern is that the fleet is heavily fishing particular areas then moving on when catches drop. It is therefore possible that the overall CPUE may mask severe local depletions and a decline in the overall stock.

To investigate the possibility of local depletions in the ray assemblage, the distribution of daily CPUE of ray licensed vessels was investigated on an annual basis for those grid squares fished by the ray fleet. The midday positions of fishing ray licensed vessels were distributed over 124 grid squares. However, on occasion the midday position of a vessel may bear little relation to its actual fishing position. To remove grid squares fished only occasionally, or which were incidental positions of a steaming vessel, only grid squares with more than ten daily catch reports over the course of the licensed fishery were considered. For each of the 56 grid squares that met this criterion we investigated the distribution of daily CPUE by ray licensed vessels on an annual basis. This was explored further by fitting a linear regression of daily CPUE on year for each of the grids.

Distribution of rajid species

Attempts to infer the distribution patterns of the different rajids in the fishery from observer data are confounded by limited temporal and spatial coverage and the possibility of migrations by some species. To provide a consistent estimate of the variation in distribution over a wide area and wide depth range, a research cruise was undertaken from 26 July to 3 August 2000 using the research and patrol vessel *Dorada*. Five cross-slope transects were placed to cover the main area fished by the licensed ray fleet on the slope north of the Falklands (Fig. 3). Trawls were to be carried out at depths of 120 – 150 m (“150 m”), 200–250 m (“200 m”) and 350–400 m (“350 m”) on each transect. A standard commercial bottom trawl with a “tickler” chain and a 40 mm codend liner was used. Tows lasted approximately 1 hour at a towing speed of 3.5 knots. Weather conditions prevented fishing of the deepest station on transect R3 and the stations on R4. All rays caught were identified to species and catches recorded both in catch weight and number of individuals.

Migration

As noted above the biological data collected by observers on ray licensed vessels is necessarily restricted in both temporal and spatial coverage. However in 2000 and 2001 it proved possible to place observers on ships for two periods of the ray fishery. Data from these trips (in September and October/November 2000 and August and November 2001) has been used to investigate migrations of two species: *Raja flavirostris* and *Bathyraja griseocauda*. These have been chosen because anecdotal reports suggested they exhibit different migration patterns. The monthly distributions of trawl by trawl CPUE were investigated in two regions, east and west of 60°W, and two depth ranges (100–199 m and 200–299 m). Sex ratios were also calculated by depth range.

Individual species CPUE trends

Fisheries Observers identify the catch by species on a trawl by trawl basis and this allows the investigation of CPUE on a species by species basis. However, the limited observer coverage for the ray licensed fishery requires some care in the use of this data. Observers have been placed on at least one ray licensed vessel in August and/or September annually from 1992 to 2001 with the exception of 1998. To maintain temporal consistency, and so minimise the confounding effects of potential migrations, observer data from other months was not included. The mean daily fishing depths of the ray fleet and depths of observed trawls during August and September are compared in Fig. 4. It is clear that the ray fleet fished shallower areas than normal in 1997 and, to a lesser extent, in 2001. With the exception of 1996, when the observed trawls were largely considerably deeper than the mean fishing depths, the depth range of observed trawls corresponds fairly well with the mean depths fished by the entire ray fleet.

Taking the entire set of mean reported fishing depths in August and September from 1994 to 2001 the quartiles are 190 and 306 m. For observed trawl depths in these months from 1992 to 2001 the quartiles are 197 and 300 m. We have therefore restricted analysis of individual species CPUE to trawls in the depth range 200 to 300 m. For 1996 and 1997 the distribution of observed trawls means that there are relatively few stations in this depth range. We have therefore grouped the trawls into three periods, each of three years: 1992–1994 ("early"), 1995–1997 ("middle") and 1998–2001 ("late"). For the observed trawls meeting these criteria individual species CPUEs were calculated in kg per hour fished.

Diversity indices

As a preliminary exploration of the data the diversity of the northern ray fishery area was expressed using the Shannon diversity index (H) and measure of equitability (E_H). The Shannon index is commonly used to characterise species diversity in a community (Zar, 1999), and attempts to account for both the abundance and evenness of the species present. This is calculated as

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

where p_i is the proportion of species i in a sample.

Shannon's equitability (E_H) is calculated by dividing H by ln(S), where S is total number of species in the sample. Equitability assumes a value between 0 and 1, with 1 being complete evenness or homogeneity.

These measures assume that all species are equally vulnerable to the sampling gear, in this case a trawl.

The diversity indices were calculated on a trawl by trawl basis using catch weight data collected from five ray-licensed vessels operating at depths between 150–350 m during August and September 1994 to 2001 (Table 5). The trawl data were also spatially resolved into two regions, east and west of 60º W. Within these constraints, catch data are limited, and there is little overlap between vessels and year.

To further investigate the effects of depth, diversity indices were calculated based on data from eleven research trawls (see distribution of rajid species section above). For each trawl, the proportion of species was expressed both in terms of catch weight and number of individuals caught.

Results

Stock assessment

The new assessment provides a higher estimate of initial biomass (B_0), and potentially higher MSY, than that reported by Agnew *et al*. (2000) (Table 4). However, confidence limits for all parameters remain wide and for B_o are highly skewed

Although the model parameters derived from the previous assessment, combining areas 1 and 2, yielded lower estimates of annual biomass, both analyses reveal a number of consistent trends. Indeed, raising the previous annual biomass by the latest estimate of B_0 demonstrates they both have similar trajectories (Fig. 5). High catches during the early-1990s reduced the initial stock biomass by approximately 30% by 1995. Following this decline in biomass fishing effort was reduced in the latter half of the decade. The substantial reduction in effort observed in 1998 was due primarily to the Korean financial crisis that prevented many vessels operating in the fishery. An increase in the stock biomass was also apparent in the late-1990s.

Agnew *et al*. (2000) noted that the mean disk width of one species in particular, *Raja flavirostris*, had decreased between 1993 and 1999. This is one of the largest target species caught within the FICZ and a reduction in the mean size in catches is potentially the result of a high level of fishing pressure. However, it is known that this species is widely distributed on the Patagonian Shelf and there may not be a distinct stock within Falkland Island waters (see Cousseau and Perrotta, 2000).

Raja flavirostris (also reported as *Dipturus chilensis*) is subject to heavy fishing pressure within the Argentine EEZ (García de la Rosa *et al*., 2000). Although catch statistics indicate rajids have been exploited within the Argentine EEZ since 1985 it was not until 1994 that total annual catches began to exceed 6,000 tons. This increase in catches within Argentine waters could be linked to the observed decline in catch rates reported within the FICZ during mid-1990s. To investigate this hypothesis an additional assessment was conducted which combined both Falkland Island and Argentine catch statistics (see Table 3). An improvement of the model fit, indicated by a substantially higher overall goodness of fit (e.g. R^2), might suggest that part of the Falkland Island skate and ray stock was exploited elsewhere. However, inclusion of the Argentine catch data actually reduced the overall fit from 0.909 to 0.876 and greatly increased the confidence limits for each parameter. This provides some evidence that the bulk of the northern skate and ray stock is self-contained.

Local CPUE trends

Mapping the catch and effort of the ray licensed fleet demonstrates that the area fished by the fleet varies from year to year and within a year (
Fig. 6) illustrating that the possibility of local depletion should be considered. However when the distribution of daily CPUE was investigated for each grid square on an annual basis no consistent trends were immediately apparent. Eighteen grid squares showed a significant linear trend when daily CPUE was regressed against year over the period 1994–2001 but only in two cases was this trend negative. The annual distribution of CPUE is illustrated for these eighteen squares in Fig. 7. It is clear that there is significant intra-annual variability in CPUE in each grid square. Furthermore, the trends are not necessarily well described by a simple linear regression. Several of the grid squares with a positive linear trend show a decrease in CPUE between 1994 and the 1996/1997 before CPUE increases again. The two grid squares where a linear regression produced a negative slope have only been fished by the ray fleet in a limited number of years.

Distribution of rajid species

The proportion of different ray species, in terms of both catch weight and numbers caught, at the eleven research trawl stations fished between 26 July and 3 August 2000 is illustrated in Fig. 8. *Bathyraja albomaculata* was present at all stations. *Bathyraja brachyurops* was caught only at the 150 and 200 m stations with a noticeable increase in proportion of the catch on the eastern transect, R5. With the exception of the 350 m station on R1 *Raja flavirostris* was also only caught at the 150 m and 200 m stations, but was entirely absent from the eastern transect.

The smaller *Raja doellojuradoi* was present at all 200 m and 350 m stations but was caught only, at low abundance, at two of the 150 m stations. *Bathyraja griseocauda* was a significant component of the catch at the 200 and 350 m stations but formed just a small part of the catch at two of the 150 m stations. The occurrence and proportion of the undescribed *Bathyraja* sp. #3 in catches increased with depth. *Bathraya multispinus* and *B. scaphiops* also increased in occurrence and proportion of the catch in the deeper stations. *Psammobatis* spp. were restricted to the 150 m stations. On the three more westerly transects *Bathyraja macloviana* occurred only at the 150 and 250 m stations, but was present at the 200 m station on the eastern transect.

Migration

In *Raja flavirostris* (Fig. 9) in 2000 the shallower trawls west of 60°W have considerably higher CPUE than those east of 60°W. In the western region there is a decline in CPUE from September through to November. A similar decline is seen in the deeper trawls although the difference between the eastern and western regions is less marked. In 2001 there is a similar pattern in the 100–199 m depth range. In trawls in the 200–299 m depth range CPUE is considerably higher in the eastern region in August. By November, however, CPUE has declined in the eastern region but increased in the west.

The basic pattern of a decline in CPUE of *Raja flavirostris* over the period from August to November is consistent with a seasonal emmigration of this species. The shift in the high CPUEs in the deeper trawls in 2001 illustrates a westwards shift in the occurrence of trawls with higher CPUEs.

In *Bathyraja griseocauda* (Fig. 10) CPUE is, as expected, considerably higher in the deeper trawls than those in the shallower depth range. There are no major differences between the CPUE east and west of 60°W, nor are there consistent trends through time.

In *Raja flavirostris* (Fig. 11) there is a clear predominance of females in the catches whereas sex ratios in *Bathyraja griseocauda* are much closer to equality. The proportion of females in catches of *Raja flavirostris* is slightly higher in deeper water and increases over the period August to November.

Length frequency data (see Fig. 13) shows that few small, immature *Raja flavirostris* are found in Falklands waters, whilst all sizes of *Bathyraja griseocauda* are present. The smallest *Bathyraja griseocauda* are found in deeper water, beyond the normal ray fleet fishing depths, but present as occasional by-catch by other fleets.

Individual species CPUE trends

The distribution of CPUE for all species caught in the trawls meeting the define criteria was examined for the three year periods (Fig. 12). For some species (i.e. *Bathyraja albomaculata*, *B. brachyurops*, *B. macloviana*, and *B. scaphiops*) there is little indication of a trend in CPUE. In the two *Raja* spp. (*Raja doellojuradoi* and *Raja flavirostris*) CPUE appears to have steadily increased over the three periods, whereas in three species (*Bathyraja griseocauda*, *B. multispinis* and the undescribed *Bathyraja* sp. #3) there are indications of a decline in CPUE. The apparent decline is especially marked in the case of *B. griseocauda*, whilst the undescribed *Bathyraja* sp. #3 has apparently undergone a sharper decline with only very low CPUEs in the middle and late periods.

Maturity and size distribution

Using observer data from 2000 and 2001 only, Fig. 13 shows the proportion of mature (stage III, see Table 2) males in *Raja flavirostris* and *Bathyraja griseocauda* using 1 cm disk width classes. As noted above these two species, both of which have relatively large adults, appear to show opposite trends in CPUE over the period of the fishery. In *Raja flavirostris* 50% of males are mature at a disk width of approximately 64 cm whilst in *Bathyraja griseocauda* 50% maturity is reached at a disk with of 77 cm. Also shown in Fig. 13 is the male size frequency distribution. In *Raja flavirostsis* 12.8% of sampled males had disk widths of 64 cm and above whilst in *Bathyraja griseocauda* only 4.6% of males were above the size at 50% maturity.

Diversity

The annual distributions of the Shannon diversity and equitability indices, calculated from the commercial catch data, are illustrated in Fig. 14. Although there is notable inter-annual variation in the data there are no consistent trends in either the diversity or equitability of ray species between 1994 and 2001. Preliminary investigations of the effects of depth, utilising GLM and GAM modelling in Splus, revealed trends of diversity and equitability with depth. For instance, there was a significant negative effect of depth on the Shannon index when data between 150m and 350m were considered ($p<0.05$: Table 6). Unfortunately, the level of overlap between vessels, years and depth ranges sampled was not sufficient to allow detailed analysis of this relationship.

In none of the cases examined there was there a significant trend in diversity or equitability index with year, where trend was defined as a significant positive or negative linear relationship, either when depth was included as a factor or when it was not. If year was included as a factor, rather than as a continuous variable, it became significant. This is because there was significant inter-annual variation in the indices (Fig. 14) but no significant trend in the indices.

The diversity indices calculated for the research trawls are presented in Tables 7 to 10. When calculated in terms of proportion of catch weight both the mean diversity index and mean equitability increase slightly with depth, whereas they peak at intermediate depths (200 m) when calculated in terms of number of individuals caught. However the means for the 150 m stations are obviously influenced by the low diversity/equitability of the 150 m station on the eastern (R5) transect and, with the exception of this station, diversity and equitability do not show any great variation or consistent patterns.

Discussion

The managed fishery around the Falkland Islands has been in operation since 1987 and specific licenses allowing the targeting of rajids have been issued since 1994. The setting of allowable levels of licensed fishing effort in the ray fishery has been based on stock assessments that use a simple production model where the ray assemblage is treated as a single stock, and where the biological parameters (such as growth rate) are relatively unknown. Recognising that this cannot adequately represent the dynamics of all the species which comprise the ray assemblage around the Islands, the Falklands Islands Fisheries Department has been gathering biological data on the ray assemblage from both Fisheries Observers and research trawls. This, together with daily catch and effort data from the licensed fleet, has provided this opportunity to review the operation of the current management policies in terms of maintenance of a sustainable fishery, and of the effects on species diversity.

An updated stock assessment, based on the methods used by Agnew *et al*. (2000) suggests that the biomass of the northern ray assemblage has recovered following a decline to around 37,000 tons in the mid-1990's, reaching 46,000 tons in 1999. The biomass in 2001 is estimated at 43,000 tons. The latest assessment suggests a higher biomass through the 1990s than previously reported by Agnew *et al*. (2000). The recovery of the stock during the latter half of the 1990s suggests that the precautionary management approach adopted in the early 1990s has worked well, at least to the extent of rebuilding and maintaining the biomass of the overall assemblage. Moreover, if total catches in 1998 had remained similar to those reported in 1997 (i.e. approximately 3,000 tons), the new stock biomass in 2001 would only be 2.5% lower than the current estimate (B_{2001}). In its current form, the addition of Argentine total catch data did not improve the model fit. Due to the high level of data aggregation, there is no spatial or species-specific information on the extent of Argentine *Raja flavirostris* catches. The inclusion of Argentine catch data is unlikely to improve the assessment until the migration patterns of *R.flavirostris* are better understood. Although a simple interpretation of these results may suggest that total annual catch could increase from the current level of 4,000 tons, the slight decline in stock apparent from 1999–2001 confirms the need to maintain a precautionary approach to the management of the ray fishery and continue the limitation of allowable fishing effort.

The treatment of the northern ray stock as a single unit, together with the known variation in the spatial distribution of fishing effort from year to year, suggests the need to carefully check for the possibility of local depletions which may be masked in the overall CPUE series. Examination of CPUE series at the resolution of the 0.25° latitude by 0.5° longitude reporting grid reveals high variability in CPUE but no evidence for long term local declines.

The research cruise carried out in July-August 2000 allowed the assessment of the variation in the distribution of different ray species over a wider area than normally covered by observers on commercial vessels. Both bathymetric and geographical variation in the distribution of the species that make up the assemblage is apparent from the research data. However this represents only a "snapshot" of the rajid distributions at one point in time in a single year. Further research cruises would provide valuable insight into the spatial dynamics of the ray assemblage. Some insight into migrations of particular rajid species is possible using observer data where extended temporal coverage has been possible within a season. However varying spatial coverage, coupled with vessel effects, suggest considerable caution in the interpretation of this data. There is some evidence that *Raja flavirostris* is a migratory species, possibly migrating westwards out of the Falklands zones towards the end of the year. The predominance of females in *Raja flavirostris* is consistent with a species undertaking feeding migrations to the Falklands zones. It is often observed that females generally travel further and so predominate at the edges of a species' feeding range. This is the case, for example, in hakes (Tingley *et al*., 1995) and oceanic squids (Zuev *et al*., 1985). The increase in the proportion of females may also suggest that males are leaving to return earlier to spawning grounds elsewhere. In contrast, there is no evidence for geographical migrations by *Bathyraja griseocauda* and this species may complete its entire lifecycle within Falklands waters.

The variation in distribution and spatial dynamics of the species within the rajid assemblage obviously implies that different species will experience differential fishing mortality. Likewise variations in life history characteristics (growth rate, age/size at maturity, fecundity) will produce variation between species in their resistance to fishing pressure. The series of catch data by species from Fisheries Observers aboard the Falklands registered ray fleet has provided evidence of declining abundance in some species and increases in others. *Bathyraja griseocauda*, one of the species where a decline in abundance is apparent, is known to be a slow growing, long lived species (Gallagher, 2000) and sampling suggests that only 4.6% of males found in the fishery in 2000 and 2001 were above the size at 50% maturity. In *Raja flavirostris*, a species which shows evidence of an increase in abundance over the last decade, 12.8% of males were above the size at 50% maturity. No studies of the growth rate of *Raja flavirostris* have been carried out to date.

Changes in the species composition of a mixed species fishery comprised of species with different life histories are inevitable when the assemblage is subject to unselective fishing. The loss of slow growing, long lived species, and their replacement by faster growing species, has been a feature of several rajid fisheries across the world (see, for example, Pawson and Vince, 1999). One way to quantify the changes in diversity as a result of fishing pressure is the calculation of diversity indices, such as the Shannon index used here. The results of our diversity analysis are intruiging, if inconclusive, with respect to the relationship between biodiversity indices and depth. However, the more important finding of this analysis with respect to conservation of rajids around the Falkland Islands is that no consistent declines or increases in the indices be detected over time (1994–2002) which suggests that relative diversity is currently being conserved in this fishery. This is perhaps surprising given the observed decline in CPUE of *B. griseocauda*, and increases in that of the two *Raja* species. The results of the research trawling, however, confirm that the indices used may be relatively insensitive to the detailed species composition. In terms of diversity, as measured by the indices employed here, a decline in one species can be compensated for by an increase in another. Whilst the apparent overall maintenance of diversity is an encouraging result, it must be appreciated that this does not imply that there has been no change in the make up of the rajid species assemblage, and attention must still be given to the fate of individual species.

In conclusion, the management of the rajid fishery around the Falkland Islands appears to be successfully maintaining a sustainable fishery. Some changes in species composition are, however, apparent. Although the CPUE of several species appears to have been relatively stable over the last decade a number of species have declined whilst there have been compensatory increases in other species. Although some changes in the species composition of a mixed species assemblage subject to unselective fishing are to be expected, especially in the face of substantial variation in life histories, it is possible that some measures could be found to protect the slower growing species. The closing of the once heavily exploited area to the south of the Falklands to the directed ray fishery currently provides one refuge for species, such as *Bathyraja griseocauda*, which are not resistant to fishing pressure even when maintained within conservative limits.

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Table 1. Ray species caught in the northern multi-species fishery around the Falkland Islands, north of 52ºS.

Species	*Percentage in catch (1993-2002)*
Bathyraja griseocauda	24.18
Bathyraja albomaculata	21.97
Bathyraja brachyurops	20.38
Raja flavirostis	13.28
Bathyraja sp. #3	7.23
Bathyraja macloviana	3.92
Bathyraja scaphiops	3.50
Raja deollojuruadoi	2.44
Bathyraja multispinus	2.36
Psammbatis spp.	0.41
Bathyraja magellanica	0.34

Table 2. Maturity scale for male rajids based on clasper characteristics only, as used by observers on ray licensed vessels in the Falklands fishery.

Maturity stage	*Description*	*Characteristics*
I	Immature	Claspers do not extend beyond the tip of the pelvic fin
II	Maturing/Adolescent	Claspers are soft and flexible, and extend beyond the pelvic fins
III	Mature	Claspers are rigid and are at maximum length

Table 3. Total annual catches (tons) of skates and rays (directed and by-catch) retained by vessels operating to the north of the Falkland Islands (<52 ºS), and a tuning series of catch and effort data for Korean vessels operating in the same region between 1991 and 2000 where the total daily catch of rays exceeds 25% of the total daily catch of all species caught. Argentine total rajid catches are also available between 1987 and 1998.

Year	*Total catch (tons)*	*Catch (tons)*	*Effort (hrs)*	*Argentine total rajid catch (tons)*
1987	257	-	-	200
1988	819	-	-	500
1989	996	-	-	1,000
1990	1,074	-	-	500
1991	6,067	5,583	14,655	200
1992	3,798	2,565	11,186	800
1993	6,364	5,676	21,990	1,000
1994	4,676	4,098	11,930	6,000
1995	4,611	4,003	15,159	7,000
1996	2,992	2,411	9,678	12,000
1997	2,995	2,362	7,913	10,500
1998	851	232	612	14,000
1999	4,511	3,890	10,413	-
2000	3,437	2,643	7,891	-
2001	4,012	3,280	8,493	-

Table 4. Parameter estimates from Schaefer production model using CEDA software for 1999 and 2002 assessments (95% confidence limits available for 2002).

Parameter	*1999**	*2002*	
B_0	36,224	49,622	(30,034 – 119,416)
R	0.619	0.590	(0.348 – 0.990)
q value	$1.06E^{-05}$	$7.70E^{-06}$	($2.81E^{-0.6}$ – $1.61E^{-5}$)
MSY	5,606	7,319	(4,938 – 18,947)

* Agnew *et al*. (2000)

Table 5. Number of observed trawls from the ray-licensed fleet (1-5) operating between August and September 1994 to 2001under the FIFD fisheries observer program.

Year	*Observed vessel*				
	1	*2*	*3*	*4*	*5*
1994	11	-	-	-	-
1995	-	-	-	19	-
1996	-	53	-	-	-
1997	-	-	52	-	-
1998	-	-	-	-	-
1999	-	-	-	-	23
2000	-	38	-	-	-
2001	-	40	-	-	-

Table 6. ANOVA of a linear model between the shannon diversity index and depth. Adding Year and Region did not lead to a significant change in the residual deviance of the model. Data were restricted to 150- 350 m, and 1997 was excluded.

	Value	*Std. Error*	*t value*	P
Intercept	1.7069	0.0717	23.149	0.0000
Depth	-0.0010	0.0003	-3.5541	0.0005

Table 7. Shannon diversity index for research trawls with proportions calculated in terms of catch weight.

	R1	*R2*	*R3*	*R5*	*Mean*
150	1.30	1.42	1.44	0.77	1.23
200	1.47	1.40	1.63	1.37	1.47
350	1.68	1.41		1.48	1.52
Mean	1.48	1.41	1.54	1.21	

Table 8. Shannon diversity index for research trawls with proportions calculated in terms of numbers caught.

	R1	*R2*	*R3*	*R5*	*Mean*
150	1.49	1.54	1.68	1.06	1.44
200	1.73	1.54	1.87	1.77	1.72
350	1.70	1.41		1.58	1.56
Mean	1.64	1.49	1.78	1.47	

Table 9. Shannon equitability for research trawls with proportions calculated in terms of catch weight.

	R1	*R2*	*R3*	*R5*	*Mean*
150	0.72	0.73	0.80	0.39	0.66
200	0.76	0.78	0.74	0.66	0.73
350	0.86	0.72		0.76	0.78
Mean	0.78	0.75	0.77	0.60	

Table 10. Shannon equitability for research trawls with proportions calculated in terms of numbers caught.

	R1	*R2*	*R3*	*R5*	*Mean*
150	0.83	0.79	0.94	0.54	0.78
200	0.89	0.86	0.85	0.85	0.86
350	0.87	0.72		0.81	0.80
Mean	0.86	0.79	0.90	0.74	

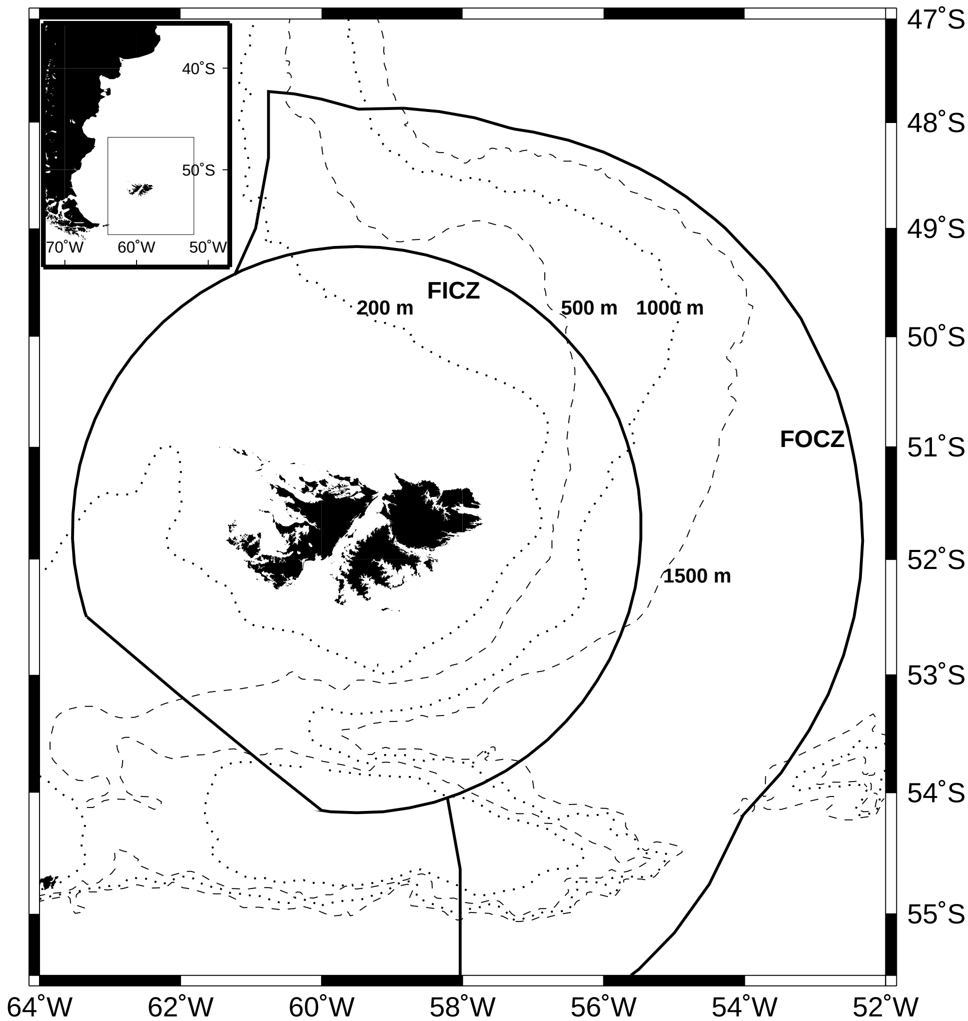


Fig. 1. The Falkland Islands and the Falkland Islands Interim Conservation and Management Zone (FICZ) and Falklands Outer Conservation Zone (FOCZ).

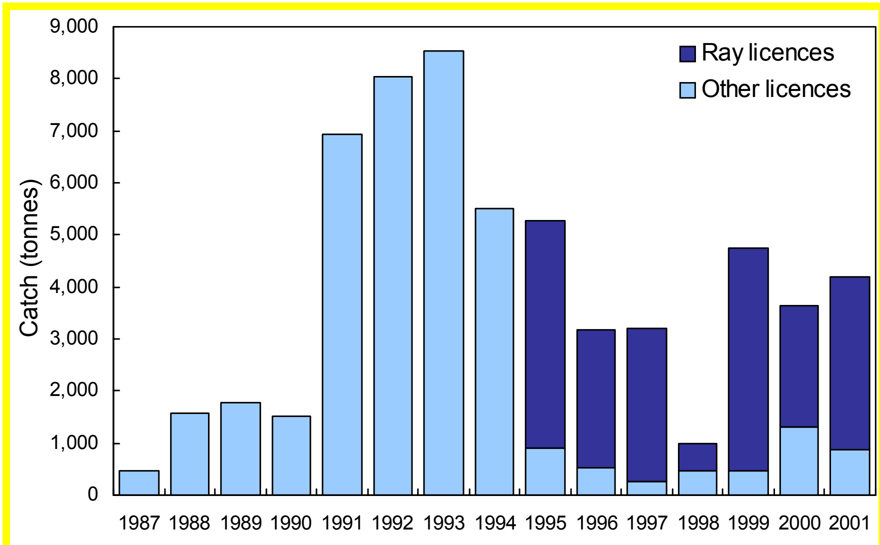


Fig. 2. Total catch of rays within the FOCZ between 1987 and 2001.

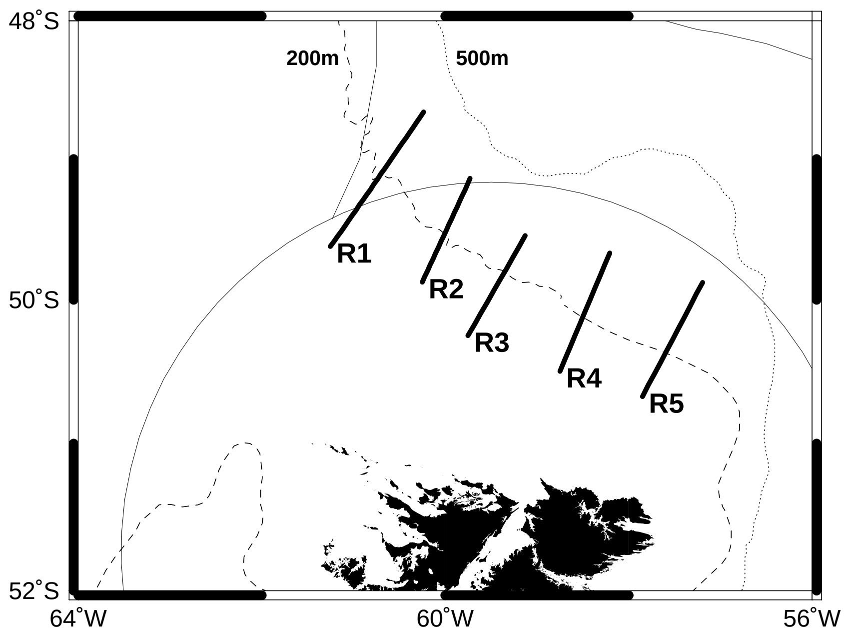


Fig. 3. Transects used for the research cruise carried out from 26 July to 3 August 2000.

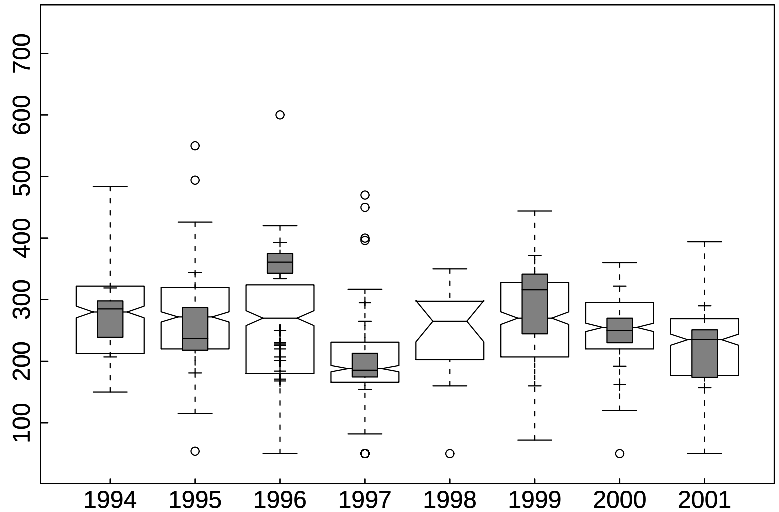


Fig. 4. The annual distribution of mean daily fishing depth of the ray licensed fleet (unfilled boxplots, circular outliers) in August and September, together with the depth distribution of observed trawls (grey boxplots, crosses marking outliers).

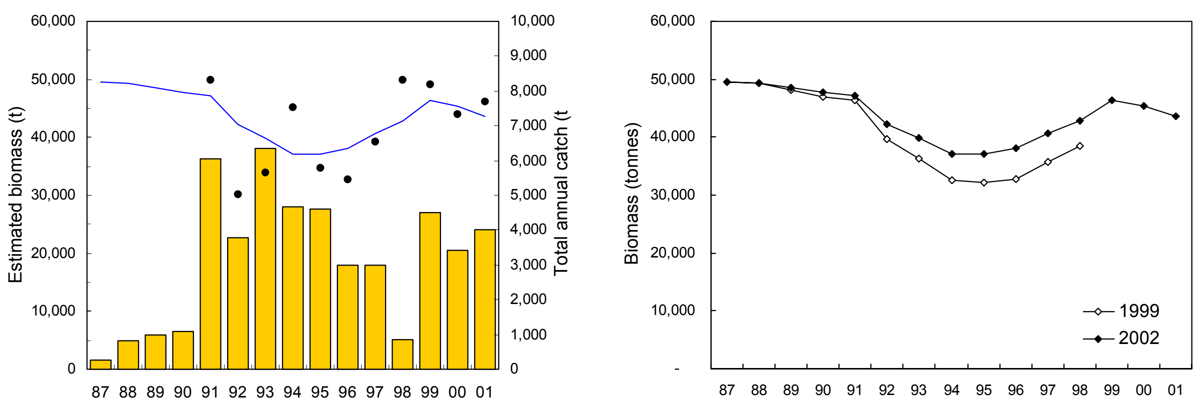
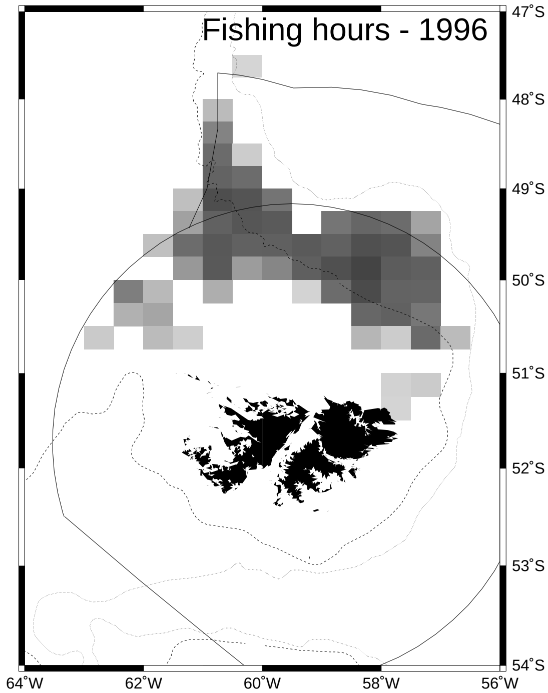


Fig. 5. Total catches (vertical bars) and estimated biomass of the northern skate and ray stock (line) and associated tuning series (circles) (left), and comparative biomass calculated from Agnew *et al*. (2000) and current assessment (right).



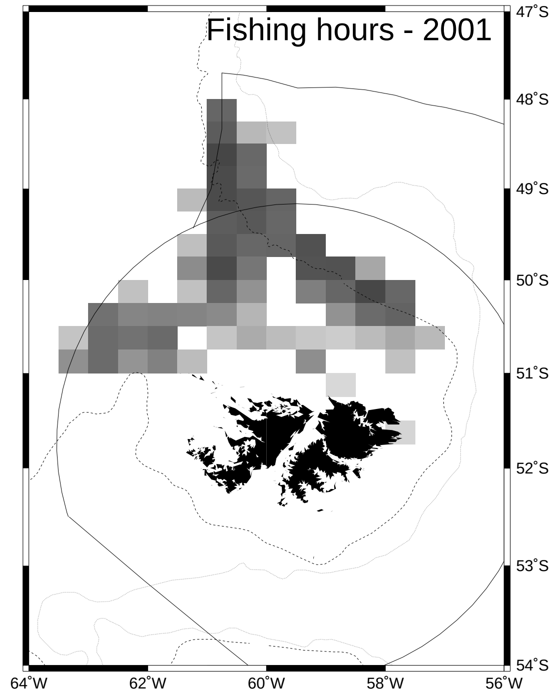


Fig. 6. The distribution of fishing effort by the ray licensed fleet in 1996 and 2001.

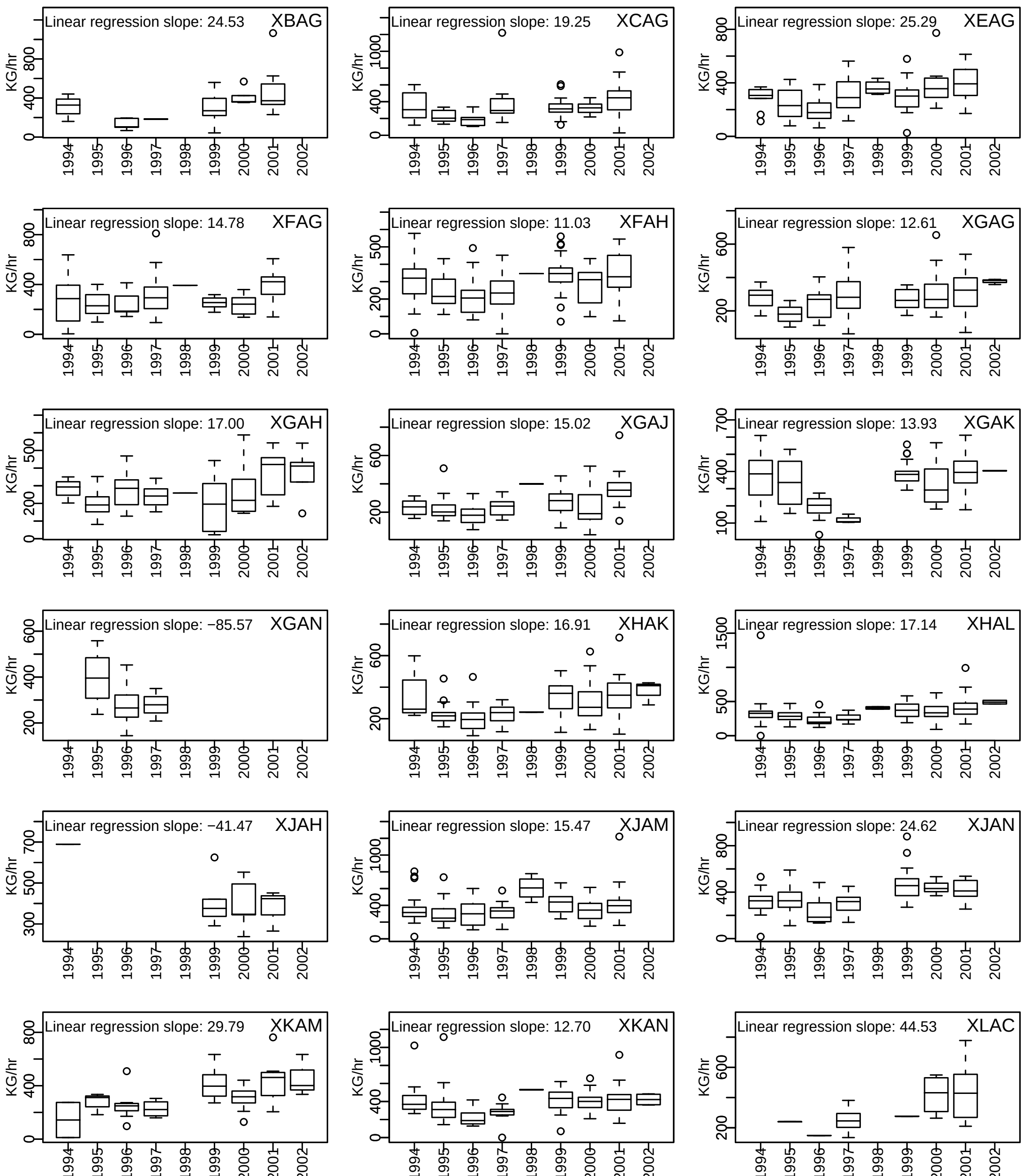


Fig. 7. The annual distribution (shown as boxplots) of daily CPUE by ray licensed vessels for those grid squares with more than 10 catch reports in the period 1994 to 2001 where a linear regression suggested a significant trend.

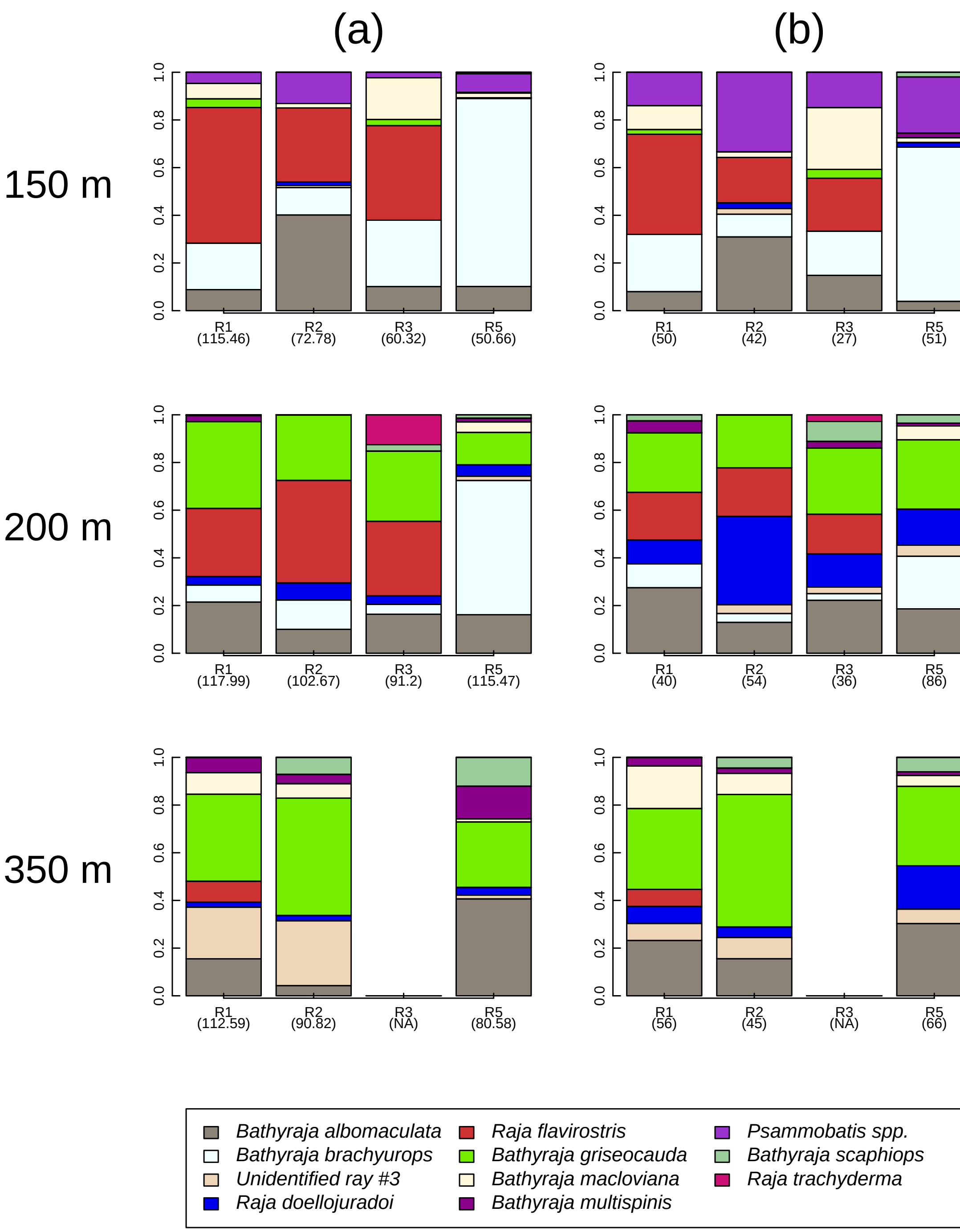


Fig. 8. Proportion of different ray species in research trawls (26 July to 3 August 2000) in terms of (a) catch weight and (b) numbers caught.

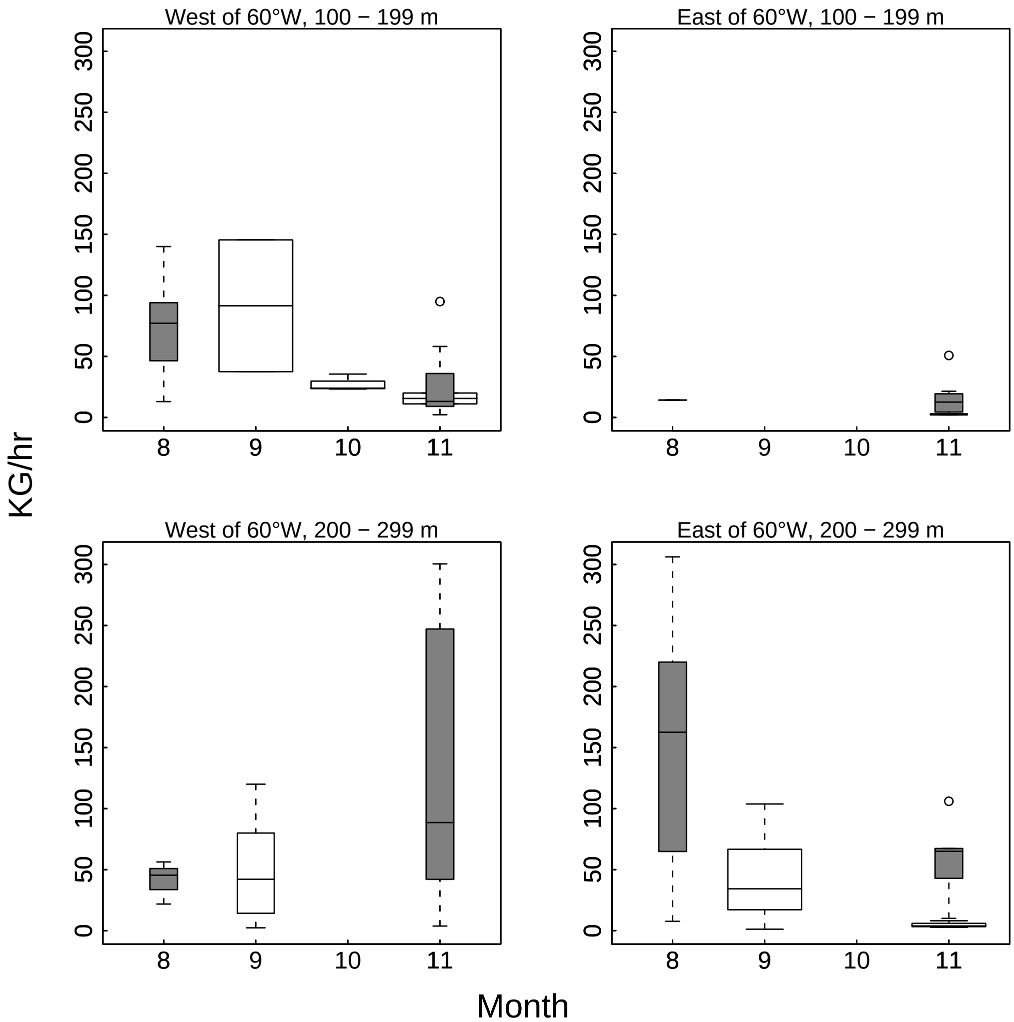


Fig. 9. Monthly distributions of trawl by trawl CPUE (KG/hr) for *Raja flavirostris*. Trawls have been divided into two regions, east and west of 60°W, and two depth ranges (100 – 199 m and 200 – 299 m). The wider, unshaded boxplots are data from 2000, whilst the narrower, grey boxplots are data from 2001.

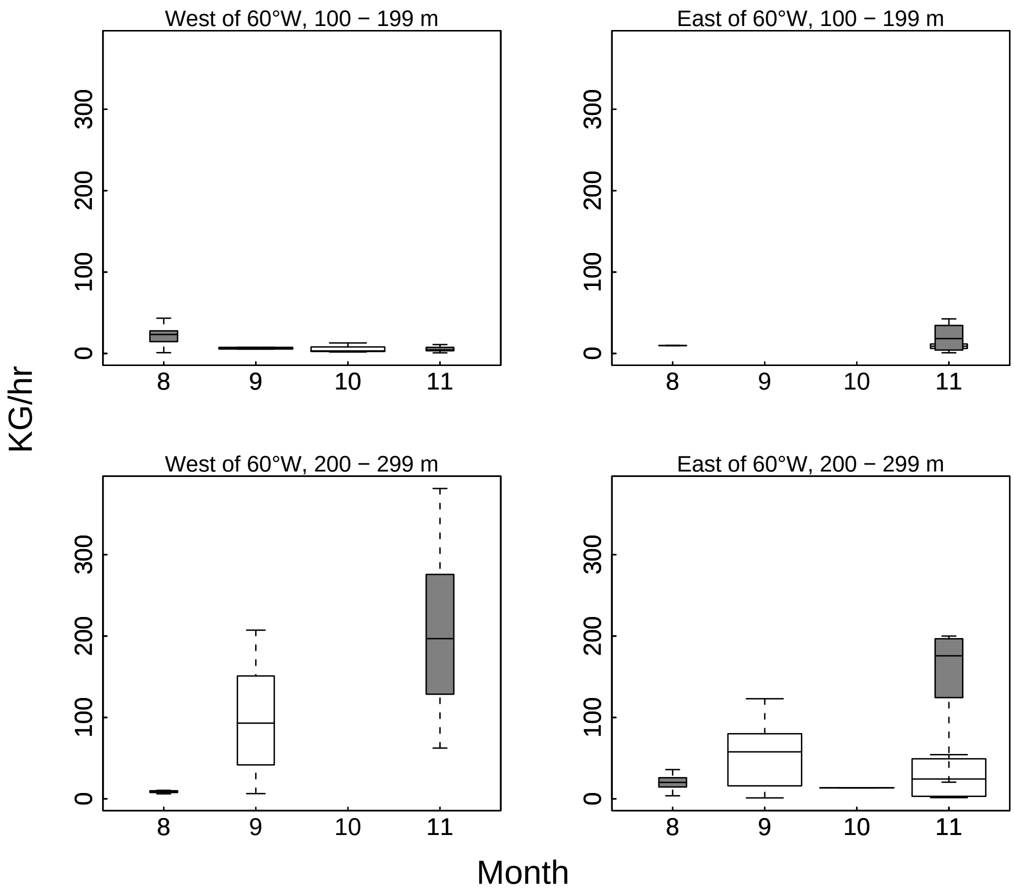


Fig. 10. Monthly distributions of trawl by trawl CPUE (KG/hr) for *Bathyraja griseocauda*. Trawls have been divided into two regions, east and west of 60°W, and two depth ranges (100 – 199 m and 200 – 299 m). The wider, unshaded boxplots are data from 2000, whilst the narrower, grey boxplots are data from 2001.

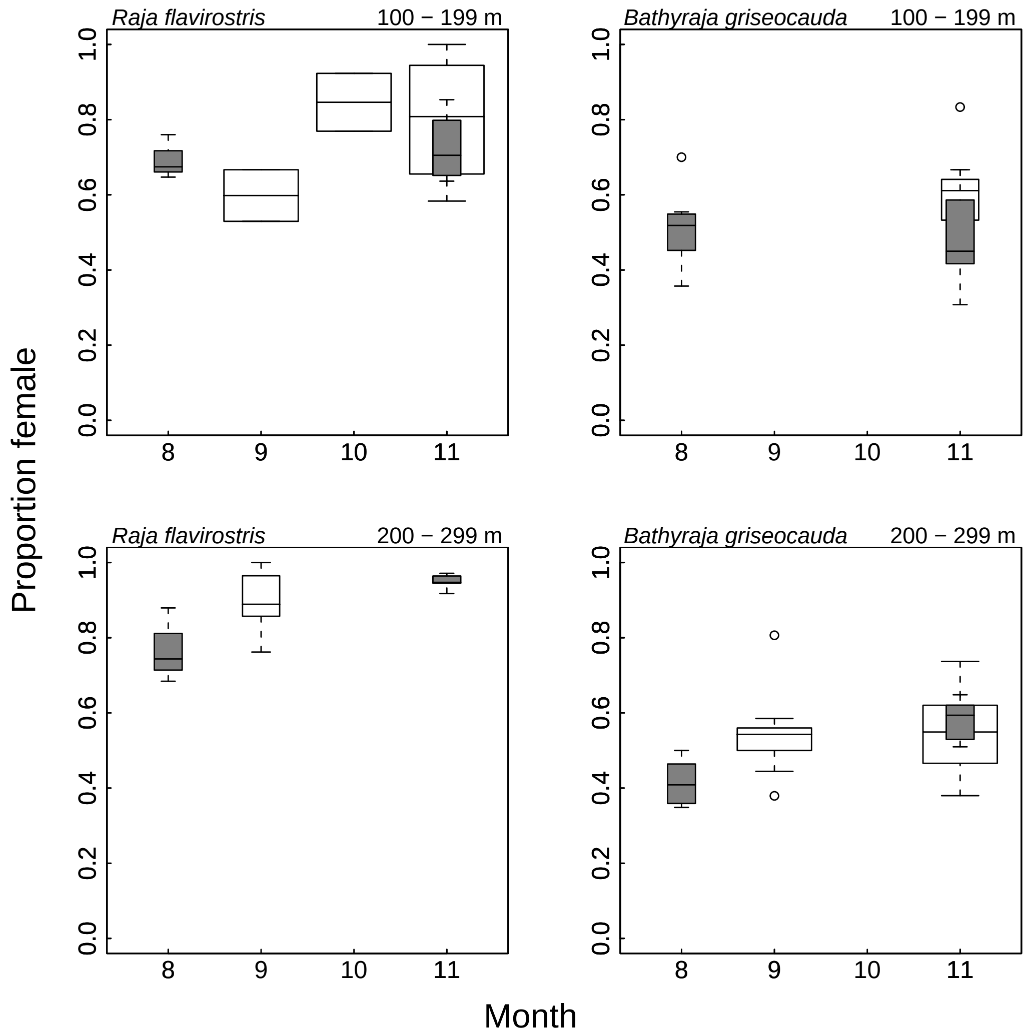


Fig. 11. The monthly distribution of the proportion of females in trawls where more than ten individuals were sexed in *Raja flavirostris* (left column) and *Bathyraja griseocauda* (right column). Trawls have been divided into two depth ranges (100 – 199 m and 200 – 299 m). The wider, unshaded boxplots are data from 2000, whilst the narrower, grey boxplots are data from 2001.

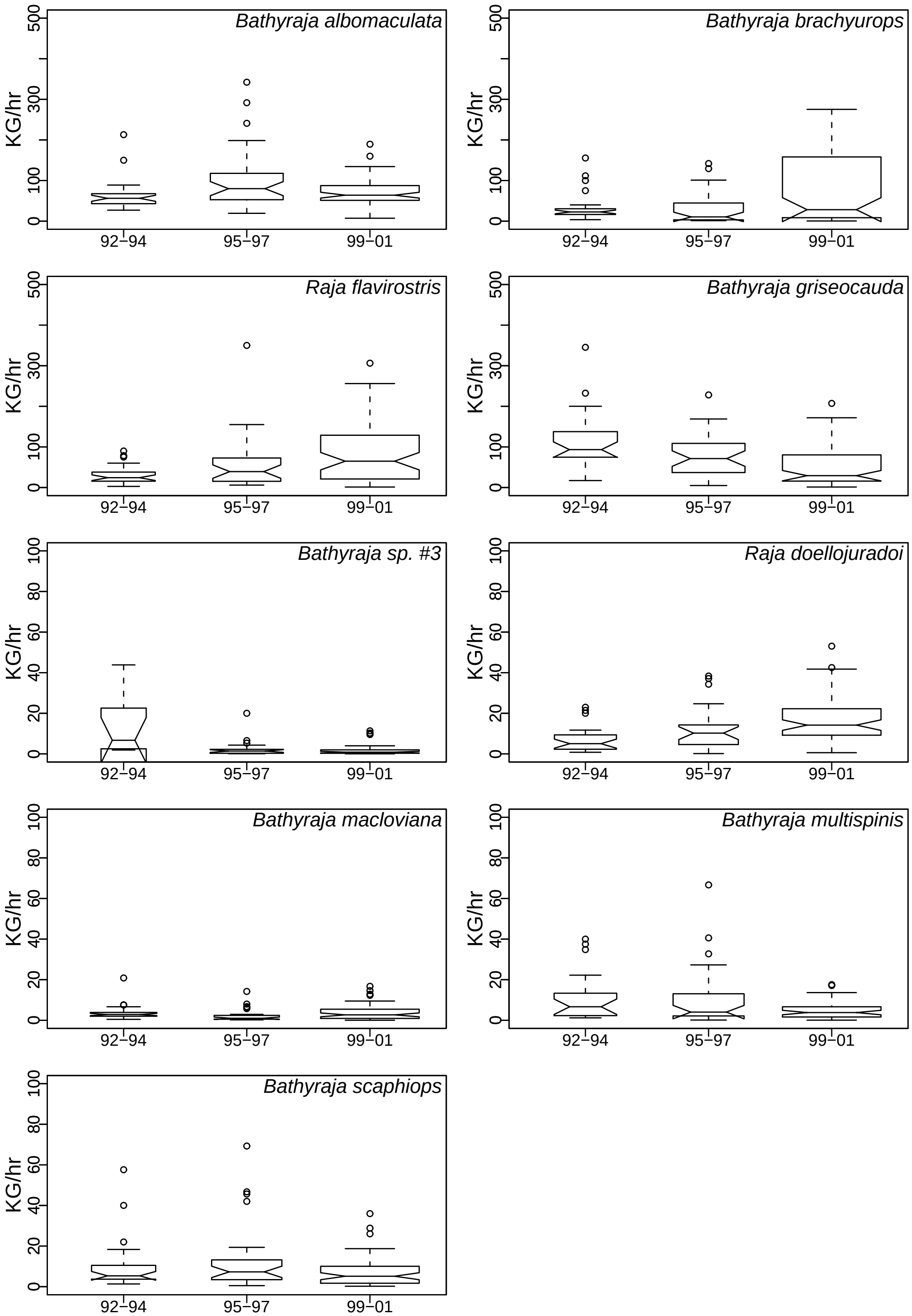


Fig. 12. Distribution of individual species CPUE from observer data using only trawls in the depth range 200 to 300 m.

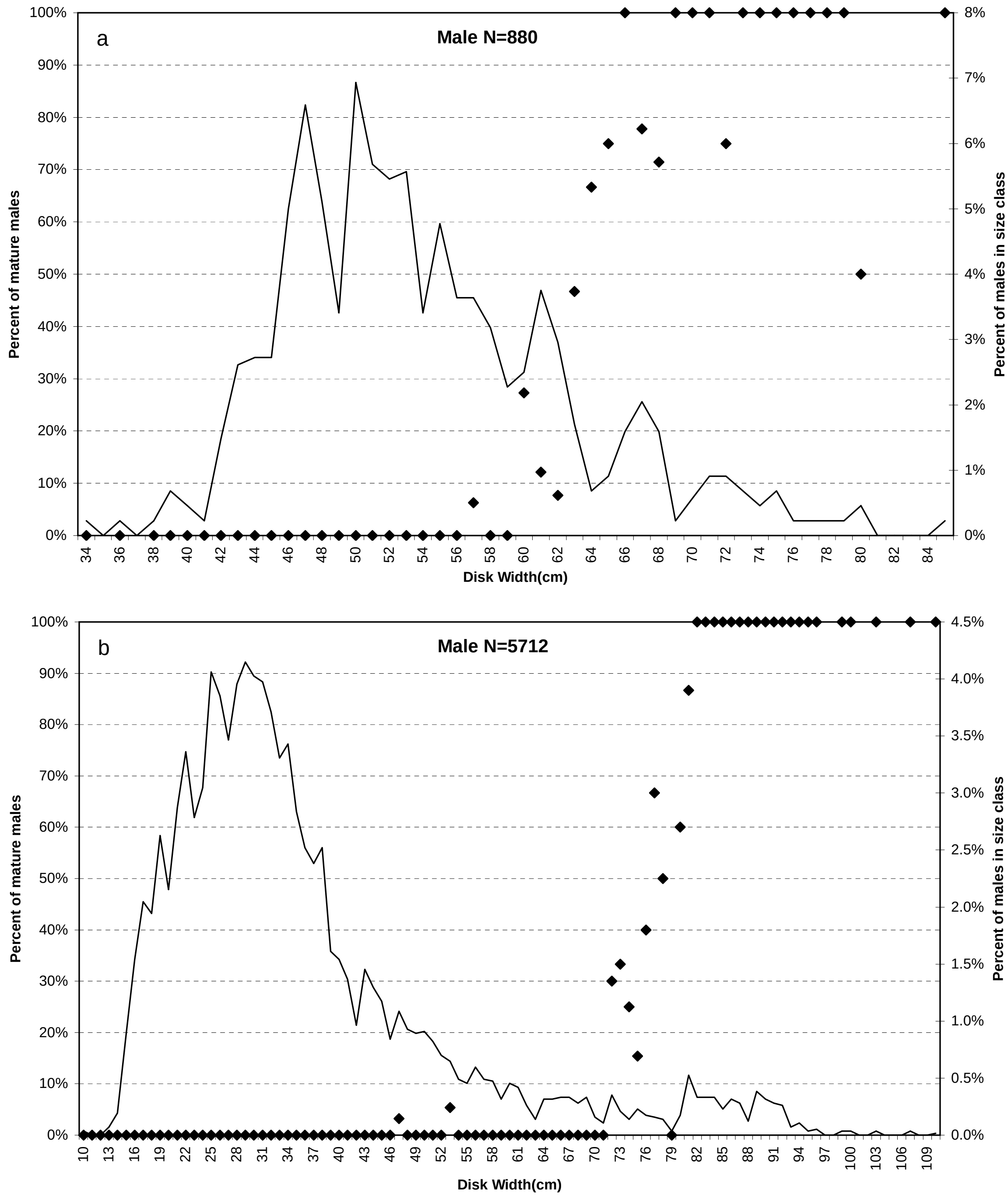


Fig. 13. The percent of mature (stage III) males by 1cm disk width class in (a) *Raja flavirostris* and (b) *Bathyraja griseocauda*, based on observer data gathered in 2000 and 2001. Also shown is the size frequency distribution for males of each species.

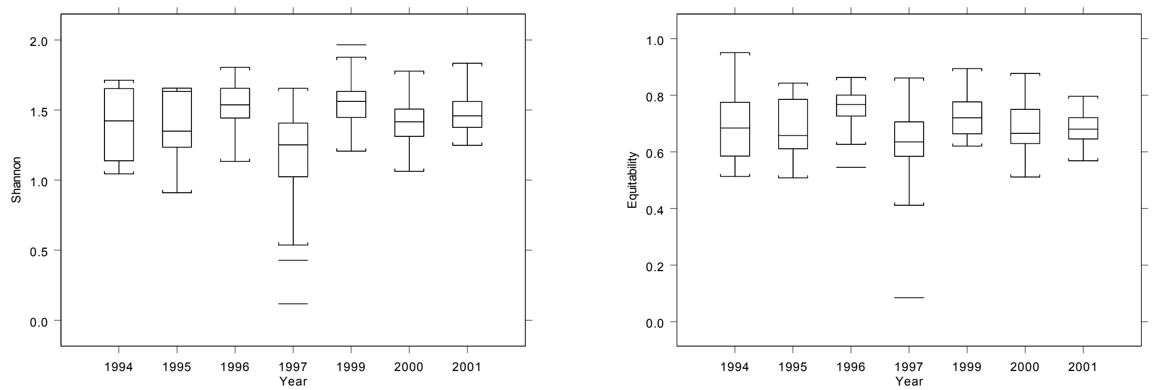


Fig. 14. Distribution of Shannon's diversity index (left) and measure of equitability (right) for skate and ray stock between 1994 and 2001. [No data available for 1998].