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BIOLOGICAL CHARACTERISTICS OF ANTARCTIC FISH STOCKS IN THE SOUTHERN SCOTIA ARC REGION

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Abstract

Commercial exploitation of finfish in the southern Scotia Arc took place from 1977/78 to 1989/90, and was in its heyday from 1977/78 to 1981/82. Except for Elephant Island, the state of fish stocks of the southern Scotia Arc region has been accorded little attention until 1998, despite substantial catches in the first four years of the fishery and ample opportunity to sample these catches. The only scientific surveys of these stocks during these years were conducted by Germany in 1985, and by Spain in 1987 and 1991. More recently, the US Antarctic Marine Living Resources (US AMLR) Program carried out two extensive surveys around Elephant Island and the lower South Shetland Islands in March 1998 and around the South Orkney Islands in March 1999. In this paper, the authors present new data on species composition, species groups, length compositions, length–weight relationships, length at sexual maturity and length at first spawning, gonadosomatic indices and oocyte diameter.

Lesser Antarctic or peri-Antarctic species predominated in the fish fauna. Species groups differed by up to 55–60% from one shelf area to the other, mostly due to differences in the abundance of the predominant species on each shelf area and the increase in the number of high-Antarctic species in the South Orkney Islands. Length compositions and the proportion of large (= old) specimens in the populations provided no evidence of illegal fishing since the closure of the region some 10 years ago. Differences in length–weight relationships between areas were primarily due to differences in length compositions of the fish caught, but did not suggest geographical differences in length-to-weight growth. Differences in estimates of length at sexual maturity and length at first spawning indicate that in some species final maturation of the gonads takes one year or more, whereas in others gonad maturation was completed within one season. Length at sexual maturity and length at first spawning in *Champsocephalus gunnari* was one year later on the southerly grounds than at South Georgia. The distribution of gonadosomatic indices in March suggested that *Lepidonotothen squamifrons* was spawning while *Trematomus hansoni* was already coming to the end of its reproductive season. *Chionodraco rastrospinosus* and *Trematomus eulepidotus* were close to spawning. Other species, such as *Notothenia rossii* and *Pseudochaenichthys georgianus*, spawn at least one to two months later than at South Georgia. Channichthyids (except *C. gunnari*), *Notothenia rossii* and *Notothenia coriiceps* have egg diameters of 4.3–5.2 mm at spawning. The *Trematomus* species investigated have egg diameters of 2.8–3.2 mm while in species of the genera *Gobionotothen* and *Lepidonotothen*, egg diameters rarely exceeded 2.0 mm. Measurements of oocyte diameters confirmed the findings on spawning time estimated from gonadosomatic indices.

Résumé

L'exploitation commercial du poisson dans la région de l'arc Scotia du Sud qui a eu lieu de 1977/78 à 1989/90 a connu ses plus beaux jours de 1977/78 à 1981/82. L'état des stocks de poissons de la région de l'arc Scotia du Sud, à l'exception de ceux de l'île Éléphant, n'a guère attiré l'attention jusqu'en 1998, malgré les grosses captures des quatre premières années de la pêcherie et les nombreuses occasions d'échantillonner ces captures. Les seules campagnes d'évaluation scientifiques menées sur ces stocks à cette époque l'ont été par l'Allemagne en 1985 et par l'Espagne en 1987 et 1991. Plus tard, le programme des ressources marines vivantes des États-Unis (US AMLR) a entrepris deux grandes campagnes d'évaluation autour de l'île Éléphant et au sud des îles Shetland du Sud en mars 1998 et autour des Orcades du Sud en mars 1999. Dans ce document, les auteurs présentent de nouvelles données sur la composition des espèces, les groupes d'espèces, la composition en longueurs, les rapports longueur–poids, la longueur à la maturité sexuelle et à la première reproduction, les indices gonadosomatiques et le diamètre de l'ovocyte.

La faune ichtyologique comprend moins d'espèces antarctiques ou subantarctiques. Les groupes d'espèces diffèrent jusqu'à 55–60% d'un secteur du plateau à un autre, en raison principalement des différences d'abondance des espèces prédominantes dans chacune des régions du plateau et de l'augmentation du nombre d'espèces de hautes latitudes de l'Antarctique dans les Orcades du Sud. La composition en longueur et la proportion de spécimens de grande taille (c.-à-d. âgés) dans les populations ne laissent pas à penser qu'il y ait eu de pêche illégale depuis la fermeture de la région il y a une dizaine d'années. Les différences dans les rapports longueur–poids d'une région à une autre s'expliquent principalement par des différences de composition en longueurs des poissons capturés, et non pas des différences géographiques de la croissance en longueur selon le poids. Les différences dans les estimations de la longueur à la maturité sexuelle et à la première reproduction indiquent que chez certaines espèces la maturation finale des gonades se déroule sur un an ou plus, alors que chez d'autres espèces, elle se produit en une saison. La longueur à la maturité sexuelle et à la première reproduction de *Champsocephalus gunnari* est atteinte un an plus tard dans les régions les plus au sud qu'en Géorgie du Sud. La distribution des indices gonadosomatiques en mars laisse entendre qu'alors que *Lepidonotothen squamifrons* était en période de ponte, *Trematomus hansoni* terminait sa saison de reproduction. *Chionodraco rastrospinosus* et *Trematomus eulepidotus* étaient sur le point de se reproduire. D'autres espèces, telles que *Notothenia rossii* et *Pseudochaenichthys georgianus*, se reproduisent au minimum un ou deux mois plus tard qu'en Géorgie du Sud. Les Channichthyidés (à l'exception de *C. gunnari*), *Notothenia rossii* et *Notothenia coriiceps* pondent des œufs d'un diamètre de 4,3–5,2 mm. Les espèces étudiées de *Trematomus* produisent des œufs d'un diamètre de 2,8–3,2 mm alors que chez les espèces du genre *Gobionotothen* et *Lepidonotothen*, les œufs dépassent rarement 2,0 mm de diamètre. Les mesures du diamètre des ovocytes confirment les estimations de l'époque de la reproduction établies à partir des indices gonadosomatiques.

Резюме

Коммерческий промысел рыбы в южной части дуги Скотия велся с 1977/78 по 1989/90 гг. и достиг расцвета в 1977/78–1981/82 гг. За исключением о-ва Элефант, состоянию рыбных запасов в южной части дуги Скотия до 1998 г. уделялось недостаточно внимания, несмотря на значительный вылов в первые 4 года промысла и прекрасную возможность для отбора образцов из этих уловов. В течение этого периода научно-исследовательские съемки запасов были проведены только Германией в 1985 г. и Испанией в 1987 и 1991 гг. Недавно в рамках американской Программы изучения морских живых ресурсов Антарктики (US AMLR) были проведены 2 крупные съемки: в районе о-ва Элефант и нижней части Южных Шетландских о-вов в марте 1998 г. и вокруг Южных Оркнейских о-вов в марте 1999 г. В этой статье авторы представляют новые данные по видовому составу, видовым группам, размерному составу, отношению длина–вес, длине при достижении половозрелости и при первом нересте, гонадосоматическим индексам и по диаметру ооцитов.

Среди рыб преобладали западно-антарктические и пери-антарктические виды. Между шельфами разница в видовых группах доходила до 55–60%, в основном за счет различной численности преобладающих видов на каждом шельфе и увеличения числа высокоширотных антарктических видов у Южных Оркнейских о-вов. Размерный состав и доля крупных (= старых) особей в популяциях не указывают на ведение незаконного промысла со времени закрытия региона около 10 лет назад. Различия в отношении длина–вес между регионами были в основном связаны с различным размерным составом пойманной рыбы и не свидетельствовали о географических различиях в росте длины с весом. Разница в оценках длины при достижении половозрелости и при первом нересте говорит о том, что у некоторых видов окончательное созревание гонад занимает не меньше года, в то время как у других видов созревание гонад происходит за один сезон. Длина *Champsocephalus gunnari* при достижении половозрелости и при первом нересте на более южных участках отставала на год по сравнению с Южной Георгией. Распределение гонадосоматических индексов в марте указывает на нерест *Lepidonotothen squamifrons*, но в то же время на завершение репродуктивного сезона у *Trematomus hansoni*. *Chionodraco rastrospinosus* и *Trematomus eulepidotus* были в преднерестовом состоянии. Другие виды, такие как *Notothenia rossii* и *Pseudochaenichthys georgianus*, нерестились по крайней мере на 1–2 месяца позже, чем у Южной Георгии. Диаметр икры при нересте у белокровных рыб (за исключением *C. gunnari*), *Notothenia rossii* и *Notothenia coriiceps* был 4.3–5.2 мм, у изучавшихся видов *Trematomus* – 2.8–3.2 мм, а у родов *Gobionotothen* и *Lepidonotothen* он редко превышал 2.0 мм. Измерения диаметров ооцитов подтвердили выводы о времени нереста по гонадосоматическим индексам.

Resumen

La explotación comercial de peces en la zona sur del arco de Escocia se llevó a cabo de 1977/78 a 1989/90, y tuvo su auge en el período de 1977/78 a 1981/82. Exceptuando los stocks de isla Elefante, hasta 1998 poco se había estudiado el estado de las poblaciones de peces de la región sur del arco de Escocia, a pesar de que durante los primeros cuatro años de la pesquería comercial se extrajeron capturas substanciales y hubo amplia oportunidad de muestrear dichas capturas. En esos años, Alemania (en 1985) y España (en 1987 y 1991) fueron los únicos países que llevaron a cabo prospecciones científicas de estas poblaciones. Más recientemente, el programa de los recursos vivos marinos antárticos de Estados Unidos (AMLR) llevó a cabo dos extensas prospecciones alrededor de la isla Elefante y al sur de las islas Shetland del Sur en marzo de 1998, y alrededor de las islas Orcadas del Sur en marzo de 1999. En este documento, los autores presentan nueva información sobre la composición por especie, grupos de especies, composición por talla, relación talla/peso, talla de madurez sexual y del primer desove, índices gonadosomáticos y diámetro de los oocitos.

En la fauna íctica predominaron las especies del oeste de la Antártida o peri-antárticas. La diferencia entre los grupos de especies de distintas zonas de la plataforma fue de un 55 a 60%, debido en su mayor parte a diferencias en la abundancia de las especies predominantes en cada zona de la plataforma y al aumento del número de especie de latitudes altas en las islas Orcadas del Sur. El examen de la composición por tallas y de la proporción de ejemplares de peces de gran tamaño (es decir, viejos) en las poblaciones de estudio no mostró evidencia de que se haya realizado la pesca ilegal desde que se impuso la veda de la pesca hace unos 10 años. Las diferencias entre la relación talla/peso observadas en cada área se deben en su mayor parte a las diferencias en la composición por talla de los peces capturados, pero no hay indicaciones de que existan diferencias geográficas en relación a la tasa de crecimiento talla/peso. Las diferencias en las estimaciones de la talla de madurez sexual y del primer desove indican que en algunos peces la maduración completa de las gónadas toma por lo menos un año, mientras que en otros el proceso de maduración habría ocurrido dentro en una temporada. La talla de madurez sexual y del primer desove de *Champsocephalus gunnari* de las regiones australes se alcanzó un año después que en Georgia del Sur. La distribución de los índices gonadosomáticos indica que en marzo la especie *Lepidonotothen squamifrons* estaba desovando mientras que *Trematomus hansoni* estaba terminando su temporada de reproducción y *Chionodraco rastrospinosus* y *Trematomus eulepidotus* estaban por comenzar el desove. Otras especies, como *Notothenia rossii* y *Pseudochaenichthys georgianus*, desovan por lo menos uno o dos meses después que en Georgia del Sur. El diámetro de los huevos de los caeníctidos (excepto *C. gunnari*), *Notothenia rossii* y *Notothenia coriiceps* en el desove es de 4,3 a 5,2 mm. El diámetro de los huevos de la especie *Trematomus* estudiada es de 2,8 a 3,2 mm, mientras que para los géneros *Gobionotothen* y *Lepidonotothen* éste rara vez excede de 2,0 mm. La medición del diámetro de los oocitos confirmó las observaciones sobre la época de desove estimada a partir de los índices gonadosomáticos.

Keywords: trawl surveys, finfish, species and length composition, length–weight relationship, maturity, spawning, gonadosomatic indices, Scotia Arc, CCAMLR

INTRODUCTION

Antarctic waters have been commercially exploited by trawl fishing since the second half of the 1960s, principally by fleets from the ex-Soviet Union and other former Eastern Bloc countries. The fishery in the Atlantic Ocean sector began on the stock of *Notothenia rossii* at South Georgia. The stock was depleted within two seasons after about 500 000 tonnes had been taken (CCAMLR, 1990a). After some years of low fishing effort, the fishery switched to the icefish *Champsocephalus gunnari* and later the nototheniid *Patagonotothen guntheri* around Shag Rocks, with some of the by-catch species, such as *Gobionotothen gibberifrons* and *Pseudochaenichthys georgianus*, being taken in substantial numbers in single years. The fishery was extended to the island shelves of the southern Scotia Arc from 1977/78 onwards. Myctophids (mostly *Electrona carlsbergi*) came into the fishery for some years in the late 1980s. Since the early 1990s, the fishery was almost exclusively a longline fishery which targeted Patagonian toothfish (*Dissostichus eleginoides*). The South Orkney Islands, Elephant Island and the lower South Shetland Islands were closed to commercial finfishing after the 1989/90 season (CCAMLR, 1990b).

Biological investigations of fish stocks in the Atlantic Ocean sector of the Southern Ocean concentrated mostly on commercially exploited fish stocks around South Georgia (Subarea 48.3) (Permitin and Silyanova, 1971; Permitin and Tarverdiyeva, 1972; Kock, 1986; Agnew and Moreno, 1992; Moreno et al., 1996; Agnew et al., 1998) and to some extent around Elephant Island (eastern part of Subarea 48.1) (Kock, 1986, 1989a, 1998). Information from other fishing grounds remained sparse (Sosinski, 1985; Kock, 1986; Balguerías and Quintero, 1989; Balguerías, 1991) despite substantial commercial activities in these areas from 1977/78 onwards. The South Sandwich Islands (Subarea 48.4) have only been investigated scientifically by a limited number of bottom trawl and bentho-pelagic trawl hauls in 1976 (Kock, 1978), 1987 (Balguerías and Quintero, 1989) and some longlining in 1993 (Ashford et al., 1994). The South Orkney Islands (Subarea 48.2) were surveyed by bottom trawl in 1985 (Kock, 1986), semi-pelagic trawl in 1987 (Balguerías and Quintero, 1989) and bottom trawl again in 1991 (Balguerías, 1991) after some limited research had been initially conducted in 1976 and 1978 (Kock, 1978, 1979). The South Shetland Islands (western part of Subarea 48.1) were studied incompletely by bottom trawl in 1976 (Kock, 1978) and in 1987 by a survey using a semi-pelagic trawl (Balguerías and Quintero, 1989).

After having focused on South Georgia (Everson et al., 1991, 1992, 1994; Kock, 1978, 1979; Kock et al., 1994) and Elephant Island (Kock, 1982, 1986, 1989a, 1998) from the late 1970s to the first half of the 1990s, research was intensified again in the southern Scotia Arc from 1996 onwards (Kock, 1998). A bottom trawl survey around Elephant Island and the lower South Shetland Islands to Low Island in the west was conducted in 1998. Thirty-seven hauls were carried out around Elephant Island and 35 hauls around the South Shetland Islands (Jones et al., 1998a, 1998b), in addition to the 182 hauls conducted around Elephant Island from 1978 to 1996 (Kock, 1998). In 1999, 64 hauls were used to study the distribution, abundance and biological features of fish stocks around the South Orkney Islands in more detail (Jones et al., 2000). In this study, the authors report new findings on the biology of demersal fish stocks in the southern Scotia Arc.

MATERIAL AND METHODS

Elephant Island (and the much smaller Clarence, Aspland, Eadie and O'Brien Islands) form the northernmost part of the South Shetland Island group. They are separated from the lower South Shetland Islands by a narrow trench which is in some places slightly more than 500 m deep. The South Orkney Islands are located some 150 n miles to the east of Elephant Island. The shelf areas of both island groups are separated by waters 2 000–3 000 m deep. The study area is shown in Figures 1a–1c.

This analysis was based on the catch composition of 37 bottom trawl hauls from Elephant Island (Figure 1a) and 35 hauls from the South Shetland Islands, both conducted in March 1998 (Figure 1b), and 64 hauls from the South Orkney Islands (Figure 1c) carried out in March 1999. Details on the gear used, the distribution of hauls and the sampling strategy were provided in Jones et al. (1998b) for Elephant Island and the South Shetland Islands, and Jones et al. (2000) for the South Orkney Islands. Net selectivity was negligible due to the use of small-meshed (20 mm) liners. All sampling stations (Figures 1a–1c) followed a stratified random survey design. However, they were restricted to areas where trawling conditions seemed to be moderate or good following acoustic bottom reconnaissance. Fishing was conducted only during daylight hours (i.e. between 0600 and 1900 hours local time).

Catches up to 500 kg were analysed in toto and sorted and identified to species level. A subsample of at least 500 kg was taken from the comparatively few larger samples of 0.6 to 2.5 tonnes. Total length of all individuals was measured to the nearest centimetre below. Total weight was determined to the nearest 10 g in specimens of >100 g and to the nearest gram in individuals of <100 g. Total weights and gonad weights of abundant fish species were taken at the South Orkney Islands from at least five individuals per centimetre group covering the whole length range of the species caught. Maturity was determined according to the five point scales provided by Everson (1977) and Kock and Kellermann (1991). Oocyte diameter (= largest diameter of the oocyte) in 30 fresh oocytes per individual was measured under a dissecting microscope at a magnification of 70 within an hour of hauling. The following terms have been used: GSI – gonadosomatic index, L_{50} – length at which 50% of the fish population have reached sexual maturity, and L_{m50} – length at which 50% of the fish population spawned for the first time. These have been described in detail and defined by Kock (1989a). Total length versus proportion of fish in maturity stages 2–5 and 3–5 respectively for each sex were fitted to a logistic equation (Ni and Sandeman, 1984) to estimate length at sexual maturity and length at first spawning. The area swept by the trawl was estimated from the mean spread between the tip of the wings times the distance travelled on the bottom during 30 minutes of trawling.

Abundance values for each species were standardised to numbers per square nautical mile swept by the trawl. Multivariate techniques, such as cluster analysis and multidimensional scaling (MDS), were applied to the data. This enabled species associations to be examined in order to identify their spatial structure. They also allowed for investigation of possible changes in fish groups within a shelf region or between neighbouring shelf areas on a multi-species level (Field et al., 1982; Greenstreet and Hall, 1996). The standardised abundance values were root–root transformed to reduce effects of high abundances of dominant species, such as *G. gibberifrons* or *Lepidonotothen squamifrons*, for the hierarchical clustering. A cluster dendrogram was plotted based on a Bray-Curtis similarity matrix and the group average linkage method. This similarity matrix was used to perform a non-parametric MDS ordination. The two-dimensional MDS plot was chosen for reasons of clarity of the ordination. The calculation of the Bray-Curtis similarity matrix and the iterative MDS processes were performed using the 'cluster' and 'MDS' modules of the PRIMER software package (Clarke and Warwick, 1994). Other similarity or dissimilarity measurements and cluster linkage methods revealed no significant differences from the results of the methods used. The species mostly responsible for the observed patterns of classification were identified in a SIMPER (similarity percentages) analysis (Clarke, 1993a, 1993b). The SIMPER procedure compared the average abundances and examined the contribution of each species to the average within-group similarity and between-group dissimilarity.

RESULTS

Species Composition

The species composition in the whole southern Scotia Arc (Table 1) was similar to that described by Kock (1998) for the Elephant Island region with the lesser Antarctic species (for terminology see Kock, 1992) *G. gibberifrons*, *Notothenia coriiceps*, *L. squamifrons*, *Chaenocephalus aceratus* and *C. gunnari* being the predominant species in the region. The only high-Antarctic species of some importance was *Chionodraco rastrospinosus*. Other high-Antarctic species, such as a number of *Trematomus* species and *Cryodraco antarcticus*, were present, especially at the South Orkney Islands. However, they played a negligible role in terms of weight and numbers.

Considerable differences existed in the occurrence of the most abundant species between areas (Table 1). *G. gibberifrons*, for example, was most abundant around Elephant Island and the South Orkney Islands, but less dominant around the lower South Shetland Islands. *L. squamifrons* was particularly abundant around the South Orkney Islands where pre- and postspawning concentrations were found in the northwestern part of the deeper shelf, but much less abundant around Elephant Island and the lower South Shetland Islands. *N. coriiceps* was found to be abundant around the lower South Shetland Islands due to one large haul of more than 800 kg/30 min. The number of species slightly increased from Elephant Island towards the South Shetland Islands and the South Orkney Islands with more high-Antarctic species being present.

Species Groups

Species composition appeared broadly similar in all three areas, with lesser Antarctic species, such as *G. gibberifrons*, *C. gunnari* or *C. aceratus*, forming the predominant elements of the ichthyofaunal groups in the various shelf areas. Lesser Antarctic species made up 77–92% (in numbers) of all species present. High-Antarctic species, such as *Trematomus eulepidotus* or *C. antarcticus*, were of little significance and accounted for only 7.6% (Elephant Island) to 22.6% (South Orkney Islands) in terms of all species caught. The only high-Antarctic species of some importance was *C. rastrospinosus* which made up 8.3% and 15.1% of all fish (in numbers) caught around the South Shetland Islands and the South Orkney Islands respectively.

An MDS plot revealed that species groups around Elephant Island were clearly distinct (60% dissimilarity) from the other two areas (Figure 2). The South Shetland Islands and the South Orkney Islands looked much more similar at first glance. However, a SIMPER analysis showed that the two island groups were also 57% dissimilar from each other.

Length Compositions

Length compositions are shown in Figures 3a–d. With a few exceptions, such as *N. coriiceps* or *Gymnoscopelus nicholsi*, maximum length observed was slightly larger in the Elephant Island area than at the lower South Shetlands (Figure 3a–c). The length distributions showed that for most species, such as *G. gibberifrons* or *C. rastrospinosus* (Figures 3a, b), the smaller length (age) classes were missing. In *N. rossii*, the first four age classes were absent from the catches.

Length–Weight Relationships

Measurements of six species around Elephant Island (Figures 4a, b), seven species from the lower South Shetland Islands (Figures 4a–c) and 14 species around the South Orkney Islands (Figures 4a–d) were sufficient to calculate length–weight relationships. Length–weight relationships of these species from previous cruises in the region from 1985 on have been included for comparison (Table 2). Readers are also referred to an extensive collection of length–weight relationships for some of the commercially exploited species prior to 1985 (Kock et al., 1985).

Length–weight relationships were similar for all three areas (Table 2) indicating a similar length-to-weight growth in all three regions. Differences found within a species between areas were likely to have been due to differences in the length range covered, not to actual differences between areas.

Sexual Dimorphism

Sexual dimorphism was observed in a number of channichthyids and in *Lepidonotothen nudifrons* at Elephant Island. Sexually mature males of *C. gunnari* have a bigger first dorsal fin than females (Kock, 1981). This difference in fin size was also apparent although less obvious in *C. rastrospinosus*. An apparent difference in growth was found in females and males of *C. aceratus*. Females were at least 15 cm larger than males. Males of *L. nudifrons* exhibited a distinctive dichromatism. Mature males had bright yellow or reddish unbarred fins while juvenile males and females always had fins with brownish bars.

Length at Attainment of Sexual Maturity and Length at First Spawning

Fish which have reached maturity stages 2 to 5 were defined as being sexually mature. First spawning of a species (maturity stages 3 to 5), however, may occur only some time after sexual maturity was attained. The maturation process of the gonads may occur within one season, as in *C. gunnari* and *P. georgianus*, or may take a year or more, as in *C. aceratus*.

Length at attainment of sexual maturity and length at first spawning have been estimated for four species around Elephant Island (Figures 5a–d), five species around the lower South Shetland Islands (Figures 5a–e) and nine species around the South Orkney Islands (Figures 5a–f). Results were provided in Table 3. Some results should be regarded with considerable caution: samples of *L. larseni* were taken some months prior to spawning. Testes of sexually mature males were still small and could often hardly be distinguished macroscopically from those of juvenile specimens. It is thus likely that a number of males may have been staged incorrectly as being juvenile while they were in fact already sexually mature. Estimates of length at attainment of sexual maturity and length at first spawning provided here for *L. larseni* were considerably higher than the expected values which were likely to be in the order of 12–15 cm.

Length at sexual maturity and length at first spawning was reached by males of all species at a smaller length than females. Length at first spawning for both females and males was difficult to estimate in *C. gunnari* from Elephant Island due to the large proportion of fish apparently not spawning in that season (Figure 5d). Fish should become sexually mature at 32–34 cm (Kock, 1989a).

However, even more than 50% of the fish larger than 40–45 cm had gonads in resting stage in the months prior to spawning.

Gonad Cycle and Oocyte Diameter

Gonad weights and oocyte diameters were measured mostly around the South Orkney Islands in March 1999 (Table 4). The material for the other two areas was much scarcer due to the more limited time available for sampling. Oocyte diameter was determined in 19 specimens of 6 species from Elephant Island and the South Shetland Islands, and in 124 specimens of 14 species from the South Orkney Islands (Table 5).

Only two species (*L. squamifrons* and *Trematomus hansoni*) were spawning in March or were approaching the end of their spawning season (*T. hansoni*). Three other species (*C. rastrospinosus*, *T. eulepidotus* and probably *L. nudifrons*) were either close to spawning (Elephant Island, South Shetland Islands) or began to spawn within the next two to four weeks (South Orkney Islands). All other species were at least four to eight weeks (*C. aceratus*, *C. gunnari*, *P. georgianus*, *N. coriiceps* and *N. rossii*) from spawning or were even several months from spawning (*Trematomus newnesi*, *L. larseni*, *G. gibberifrons* and *Trematomus bernacchii*). Although quantitative data were more limited from the Elephant Island–lower South Shetland Islands region, spawning appeared to start there at least two to four weeks earlier than at the South Orkney Islands. The wider range of gonad weights in *C. aceratus* may indicate that the species spawned over a range of two to three months. Other species, such as *N. coriiceps*, apparently have a more limited spawning season of only four to six weeks.

The range of egg diameters appeared to be low in most species with the exception of *C. aceratus* and possibly *C. gunnari* (Table 5). This suggests that many species spawned within a comparatively short period of four to six weeks.

DISCUSSION

The southern Scotia Arc region is influenced by two hydrographical regimes: Antarctic Circumpolar Water in the north and water from the Weddell Sea in the south which mix in the area. The influence of Weddell Sea water decreases towards the north although waters of Weddell Sea origin are still being found on the South Georgia shelf in some years. The area with the largest influence of Weddell Sea water appeared to be the South Orkney Islands which host the largest proportion of high-Antarctic fish species both in terms of numbers of species and in terms of individuals.

The benthic (= demersal) fish fauna of the shelf and upper slope areas of the whole Scotia Arc, including South Georgia and Shag Rocks, has been extensively studied by trawl surveys since the mid-1960s. The fish fauna was well known in terms of its composition and a number of its biological features around South Georgia and Elephant Island (Kock, 1992, for review, 1998; Tiedtke and Kock, 1989) but less studied at the South Shetland Islands and the South Orkney Islands.

The pelagic fish fauna was much less known than the demersal ichthyofauna. It has been intensively investigated around South Georgia by Russian researchers in the second half of the 1980s (Frolkina et al., 1998). However, little seemed to have been published in addition to a range of papers on biological aspects of some commercially interesting myctophids, such as *E. carlsbergi* (Kozlov et al., 1990; Mazhirina, 1990; Gerasimova, 1990; Filin et al., 1990). The pelagic fish fauna of the southern Scotia Arc remained, with a few exceptions among myctophids, poorly known.

The demersal fish fauna of the whole Scotia Arc is predominated by lesser Antarctic or peri-Antarctic species, such as *G. gibberifrons*, *C. aceratus* or *C. gunnari*. The composition of the fish fauna was similar in all shelf regions, although with some peculiarities in each of the areas. Due to the virtual absence of high-Antarctic species at South Georgia, the fish fauna there was somewhat impoverished compared to the southern Scotia Arc. This was particularly the case for species of the genus *Trematomus* (only *T. hansoni* present), the limited number of channichthyids present (only three species and a fourth, *Champsocephalus esox*, De Witt et al., 1976, as a vagrant from the southern Patagonian shelf), and artedidraconids (one species) and bathydraconids (two species). Some Patagonian species which were absent from the more southerly grounds, however, such as *P. guntheri* or *C. esox* were observed. A further peculiarity was the presence of the bathydraconid *Psilodraco breviceps* and the artedidraconid *Artedidraco mirus* which were endemic to the shelf of South Georgia.

The southern Scotia Arc has a richer species inventory than South Georgia due to the occurrence of a substantial number of high-Antarctic species.

These high-Antarctic species reach their northernmost distribution in the southern Scotia Arc. This referred in particular to members of the genus *Trematomus*, to channichthyids, and to members of the artedidraconid genus *Pogonophryne*. High-Antarctic species were confined to the southern Scotia Arc with a few exceptions, where single specimens of some high-Antarctic species had been swept north on to the southernmost part of the shelf of South Georgia (Kock and Stransky, 2000). High-Antarctic species made up a considerable proportion of the species inventory in the southern Scotia Arc. However with the exception of *C. rastrospinosus*, they contributed little to the abundance of the demersal fish fauna.

The composition of the demersal fish fauna was similar in all three shelf areas of the southern Scotia Arc. Causes for changes in the composition of the fish fauna between the three shelf regions were primarily due to:

(i) changes in the abundance of the most dominant lesser Antarctic species from one shelf region to the other;

(ii) changes in the abundance of *C. rastrospinosus* (3.9% of the abundance of all species at Elephant Island, 8.3% at the South Shetland Islands and 15.1% at the South Orkney Islands); and

(iii) differences in the abundance of high-Antarctic species which made up 3.6% of all species at Elephant Island, 10.1% at the South Shetland Islands and 17.4% at the South Orkney Islands.

Some separation by depth was also apparent between lesser Antarctic and high-Antarctic species. Most of the lesser Antarctic species had their maximum abundance at less than 250 m. The high-Antarctic species mostly occurred below 250 m or even deeper (Tiedtke and Kock, 1989; Kock and Stransky, 2000). It is impossible to conduct a detailed analysis of each demersal fish group (associations) on each of the shelf areas within the remit of this paper. A detailed description of the different fish groups, their shifts in composition with depth, and their change in abundance with past fishing pressure has been provided only for Elephant Island down to 500 m depth (Tiedtke and Kock, 1989; Kock and Stransky, 2000). Five fish groups, which overlapped to some extent in their bathymetric distribution, were present at Elephant Island. *G. gibberifrons* became the most abundant fish species after *C. gunnari* and *N. rossii* had been depleted by intensive fishing the area from the late 1970s to the early 1980s. This pattern of distribution along a vertical axis (depth) appeared to be similar in some areas around the lower South Shetland Islands and the South Orkney Islands. A detailed analysis of these fish associations is still pending.

Limited studies have so far been conducted in waters of less than 50 m depth due to problems encountered in trawling with larger vessels in these shallows. Everson (1970) found *N. coriiceps* to be very abundant in shallow waters off Signy Island (South Orkney Islands). Juveniles of *G. gibberifrons* belonging to age classes 0–2 (Figure 6) were caught in some numbers in waters of 20–30 m off the southwest coast of Elephant Island by a 3 m beam trawl. Early juveniles of other species, such as *P. georgianus* or *C. rastrospinosus*, were known to lead a pelagic mode of life, and were caught as single specimens, if at all, during bottom trawling. For a substantial number of species, in particular those living in high-Antarctic waters, the early juvenile stages were still unknown. Studies at Admiralty Bay and Potter Cove (King George Island, South Shetland Islands) showed that *N. coriiceps*, *N. rossii*, *G. gibberifrons* and *Harpagifer antarcticus* were abundant nearshore. Some information was made available on tissue metabolism, oxygen and carbon dioxide levels in Antarctic fish (Bacila et al., 1989; Fanta et al., 1989) and the age, growth and feeding of some nototheniids from nearshore trammel net catches (Barrera-Oro and Casaux, 1992, 1996; Casaux et al., 1990; Linkowski and Zukowski, 1980; Linkowski et al., 1983; Fanta et al., 1994). However these investigations still stemmed from very limited areas. Larger-scale studies on the distribution, abundance and biology of fish in inshore waters have yet to be conducted.

The length-frequency distributions showed that maximum length of the most abundant species was lower on all three southerly grounds compared to those from South Georgia prior to commercial exploitation. Maximum observed length in *G. gibberifrons*, *C. aceratus* and *C. gunnari* at South Georgia, for example, were 52, 75 and 62 cm while they were 47, 70 and 58 cm further to the south. The shape of the length compositions and the proportion of large (= old) specimens in the catches suggested that no substantial illegal fishing had taken place since the closure of the areas for finfishing in 1989/90 (CCAMLR, 1990b).

Length–weight relationships were similar in all three areas. They were also not very different between years as shown in comparison to data provided by Kock (1986), Kock et al., (1985) and

Balguerías and Quintero (1989). Such differences as were observed in the length–weight relationships were probably mostly due to differences in the length range sampled in the three areas and to the inhomogeneity of the sampling rather than a result of substantial differences between individual areas themselves. However, more systematic sampling, such as that conducted at the South Orkney Islands in March 1999, when five specimens per sex of each 1 cm length class were sampled over the whole length range of a given species, will help us to reveal in the future if actual differences in length–weight relationships existed between areas.

The only species spawning in March were *L. squamifrons* and *T. hansoni*. Two other species, *C. rastrospinosus* and *T. eulepidotus*, were close (two to four weeks) to spawning. Spawning in *N. rossii* and *C. aceratus* probably occurred about four to six weeks later than at South Georgia. Spawning time in *C. gunnari* and *P. georgianus* was apparently two to three months later than at South Georgia and about one month later at the South Orkney Islands than at Elephant Island. *N. coriiceps* spawns in May–June. Spawning of *T. newnesi* appeared to take place in June–July. *L. larseni* and *G. gibberifrons* reproduced in July–September. Spawning in *G. gibberifrons*, *L. larseni*, *L. squamifrons* and *N. coriiceps* seemed to take place at approximately the same time in all three areas.

Length at first spawning was apparently reached within one season in females of *G. gibberifrons*, *L. larseni*, *T. eulepidotus* and *C. rastrospinosus*. Maturation may take a year in *L. squamifrons*, *P. georgianus*, *C. gunnari* and *N. rossii*. Females of *C. aceratus* may take more than a year from attainment of sexual maturity to first spawning.

Growth curves exist for a number of species at South Georgia (Sherbich, 1976; Shust and Pinskaya, 1978; Freytag, 1980; Kock, 1981; Frolkina and Dorovskikh, 1989) and around Kerguelen (Duhamel, 1987). However, growth studies from areas to the south of South Georgia are scarce. The only published growth curves for the more southerly grounds are for *N. rossii*, and compare the two stocks at South Georgia and Elephant Island (Freytag, 1980), *N. coriiceps* and *N. rossii* from Admiralty Bay and Potter Cove (King George Island) (Linkowski and Zukowski, 1980; Barrera-Oro and Casaux, 1992, 1996), and *N. coriiceps* at Signy Island (Everson, 1970). Growth of fish species is apparently slower in the southern Scotia Arc than at South Georgia and fish attain a lower L_∞ than around South Georgia. More detailed growth studies of different species from these areas are urgently required.

Length at sexual maturity and length at first spawning were reached in males at a lower length than in females. However it was unclear from growth studies in fish populations at South Georgia if males generally remained smaller than females. Possible differences in growth between females and males varied considerably between species. L_∞ in males of *N. rossii* at South Georgia and Elephant Island and males of *C. aceratus* in the Scotia Arc region was 10 and 17 cm lower than in females respectively (Sherbich, 1976; Freytag, 1980; Gubsch, 1982; Jones et al., 1998b). In contrast, *G. gibberifrons*, *L. larseni* and *L. squamifrons* appeared to have similar growth curves in males and females (Shust and Pinskaya, 1978).

The attainment of length at sexual maturity and of length at first spawning appeared to take place a year later in *C. gunnari* in the southern Scotia Arc than at South Georgia where the species was already mature towards the end of its third year of life (Kock and Everson, 1997). Length at first spawning should be in the order of 32 to 34 cm at the South Orkney Islands, Elephant Island and the South Shetland Islands (Kock, 1989a). This was, however, not obvious from our data from the South Orkney Islands. The proportion of females caught in the critical length range of 27–32 cm, in which the first mature specimens are usually observed, was very small. This probably led to the underestimate of L_{50} of 29.5 cm. L_{50} is likely to change to 32–34 cm, similar to that in males, when more fish of this length range are studied on future cruises.

The proportion of *C. gunnari* individuals which were sexually mature but whose gonads were in the resting stage (stage 2) was almost 50% at Elephant Island. The proportion was much smaller in the other two areas, which suggested a much higher proportion of fish spawning in these areas. A substantial proportion of fish with resting gonads in the pre-spawning period is also well known in the population at South Georgia, albeit with large variations from year to year (Kock, 1989b; Everson et al., 1996). Previous investigations (Kock, 1981) suggested that the populations off Elephant Island and around the South Shetland Islands were separated from each other with little (if any) exchange. However an alternative interpretation that could not be ruled out was that *C. gunnari* in the Elephant Island–South Shetland Islands area formed only one population with the sexually mature but non-spawning part of the population mostly present in the Elephant Island area and the pre-spawning fish mostly found further to the southwest around the South Shetland

Islands. Both areas are only separated by narrow channels of depths of more than 400 to 500 m, which could probably be crossed by mobile fish species such as *C. gunnari*. A more integrated survey spanning from Shag Rocks and South Georgia to the South Shetland Islands should help to clarify the problem of stock structure in *C. gunnari* in the future.

The gonadosomatic index (GSI) of all species investigated, except one, was likely to be at least 20–25 at spawning. The only exception appeared to be *L. squamifrons* (Silyanova, 1981): we found either spent specimens in maturity stage 5/2 or specimens in stage 3, but no specimens in actual spawning condition (stage 4). The GSI in specimens of stage 3 was about 10. Egg size was 0.9–1.0 mm. Given that egg size was about 1.2–1.4 mm at spawning, it seems unlikely that the GSI would increase to more than about 15 during spawning. Spawning seemed to occur mostly in February–March, which is later than indicated by Silyanova (1981), who suggested that *L. squamifrons* spawned in spring–early summer.

Many nototheniolds in the southern Scotia Arc appear to spawn in autumn–winter (Kock and Kellermann, 1991). Only few species, such as *Chaenodraco wilsoni*, *T. hansoni* and *L. squamifrons*, spawn in late spring–summer. The range of egg diameters measured seems to be low in most species. This suggests that the spawning season is comparatively short in most species except in *C. aceratus* and *C. gunnari*. In 1986, for example, more than 85% of all females and 57% of the males of *N. coriiceps* had spawned around Elephant Island between mid-May and mid-June (Kock, 1989a).

Channichthyids with the exception of *C. gunnari*, have a rather limited range of egg sizes: 4.4–5.3 mm. Egg sizes in *C. gunnari* are only 3.2–3.7 mm (Duhamel, 1987; Kock, 1989a). Nototheniids have a much wider range of egg sizes. *N. rossii* and *N. coriiceps* have egg sizes of 4.4 to 5.0 mm (Silyanova, 1981; Kock, 1989a). Members of the genus *Trematomus*, such as *T. eulepidotus* and *T. hansoni*, have egg sizes of 2.8–3.2 mm. Egg sizes of late winter spawners, such as *L. larseni* and *G. gibberifrons*, hardly exceed 1.8–2.0 mm (Silyanova, 1981; Kock, 1989a).

Egg diameters seem to be similar over the distributional range of a species. A notable exception appears to be *T. eulepidotus*. Egg diameter at spawning was about 2.8–3.2 mm both at Elephant Island and around the South Orkney Islands. However egg diameter in a batch of eggs collected from a bottom trawl haul in the Weddell Sea, and assumed to be *T. eulepidotus*, was 4.4 mm (Riehl and Ekau, 1990). Surface structures compared in eggs from the two areas were found to be very similar. This suggests that the batch of eggs collected in the Weddell Sea did, in fact, stem from *T. eulepidotus*. Fecundity in the Weddell Sea should be much lower, given the much larger size of eggs at spawning. Further studies on the fecundity of *T. eulepidotus* will follow.

CONCLUSION

The two cruises in 1998 and 1999 have contributed considerably to improving our knowledge on basic biological parameters of demersal fish species in the southern Scotia Arc. This is particularly the case with regard to aspects such as distribution, abundance, community structure and reproduction of the abundant fish stocks. However gaps in our knowledge for some of the subareas are still substantial. Age and growth studies remain a major gap in our knowledge. Furthermore, studies between late autumn and early spring are urgently needed so that food and energy budgets for the entire year can be compiled. Emphasis should also be placed on studies on the macro-scale distribution, abundance and biology of inshore fish populations.

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Table 1: Number of species and their proportion in the catch in the Southern Scotia Arc in 1998 and 1999. (NB: data from the South Shetland Islands and Elephant Island were available in 100 m steps, while those for the South Orkney Islands were only available at 50–150, 151–250 and 251–500 m intervals).

Species	Elephant Island n = 37		Lower South Shetlands n = 35		South Orkney Islands n = 64	
	Total Weight (kg)	% Total	Total Weight(kg)	% Total	Total Weight(kg)	% Total
Demersal species						
Artedidraconidae						
Artedidraco skottsbergi	0.01	0.00				
Dolloidraco longedorsalis			0.02	0.00		
Pogonophryne spp.[1]			0.95	0.03	15.54	0.10
Bathydraconidae						
Bathydraco marri					0.05	0.00
Gerlachea australis			0.04	0.00		
Gymnodraco acuticeps	0.13	0.00	2.09	0.07	1.23	0.01
Parachaenichthys charcoti	1.83	0.03	2.86	0.09	0.42	0.00
Racovitzia glacialis			0.10	0.00	0.03	0.00
Channichthyidae						
Chaenocephalus aceratus	273.41	3.69	232.22	7.42	1 454.16	8.99
Chaenodraco wilsoni			0.15	0.01	0.58	0.00
Champsocephalus gunnari	1 447.75	19.51	283.65	9.05	502.42	3.11
Chionobathyscus dewitti			0.51	0.02		
Chionodraco rastrospinosus	144.60	1.95	200.88	6.42	923.92	5.72
Cryodraco antarcticus	18.64	0.25	21.14	0.68	27.89	0.17
Neopagetopsis ionah	1.33	0.02	7.65	0.24	2.52	0.02
Pseudochaenichthys georgianus	8.24	0.11	53.36	1.70	2 583.40	15.98
Nototheniidae						
Dissostichus mawsoni	19.33	0.26	9.41	0.30	1.90	0.01
Gobionotothen gibberifrons	5 022.27	67.68	754.86	24.11	5 061.57	31.31
Lepidonotothen larseni	18.52	0.25	11.48	0.37	33.15	0.21
Lepidonotothen nudifrons	3.66	0.05	1.62	0.05	0.70	0.00
Lepidonotothen squamifrons	198.40	2.67	109.69	3.50	5 023.29	31.07
Notothenia coriiceps	122.24	1.65	1 249.93	39.92	44.35	0.27
Notothenia rossii	23.53	0.32	18.31	0.59	273.30	1.69
Pagothenia borchgrevinki					0.04	0.00
Pleuragramma antarcticum	0.04	1.0	1.10	0.04	1.19	0.01
Trematomus bernacchii					6.35	0.04
Trematomus eulepidotus	14.61	0.20	4.33	0.14	58.42	0.36
Trematomus hansoni	0.12	0.00	1.74	0.06	21.85	0.14
Trematomus newnesi					2.50	0.02
Trematomus nicolai					0.05	0.00
Trematomus pennellii					0.19	0.00
Trematomus tokarevi			0.48	0.02	0.41	0.00
Muraenolepidae						
Muraenolepis microps[2]	2.45	0.03	1.00	0.03	3.28	0.02
Rajidae						
Bathyraja eatonii	7.11	0.10	19.47	0.62	6.74	0.04
Bathyraja maccaini	38.70	0.52	17.49	0.60	64.80	0.40
Bathyraja sp. 2	1.96	0.03	11.44	0.37	7.92	0.50
Zoarcidae						
Ophthalmolycus amberensis	0.06	0.00	1.12	0.04		
Pachycara brachycephalus	0.15	0.00	1.10	0.04		
Pelagic–Mesopelagic species						
Anotopteridae						
Anotopterus pharao	1.38	0.02				
Bathylagidae						
Bathylagus antarcticus	0.60	0.01				
Gempylidae						
Paradiplospinus gracilis	0.59	0.01	0.18	0.01	0.68	0.00
Lampridae						
Lampris immaculatus	29.80	0.40				
Microstomatidae						
Nansenia antarctica	0.01	0.00				
Myctophidae						
Electrona antarctica	2.26	0.03	2.24	0.07	12.49	0.08
Electrona carlsbergi			0.00	0.00		
Electrona spp.	0.01	0.00	0.01	0.00	0.01	0.00

Table 1 (continued)

Species	Elephant Island *n* = 37		Lower South Shetlands *n* = 35		South Orkney Islands *n* = 64	
	Total Weight (kg)	% Total	Total Weight (kg)	% Total	Total Weight (kg)	% Total
Gymnoscopelus braueri	0.04	0.00	0.07	0.00	1.04	0.00
Gymnoscopelus nicholsi	15.40	0.21	108.26	3.46	28.49	0.18
Gymnoscopelus opisthopterus	0.33	0.00	0.04	0.00		
Gymnoscopelus spp.					0.14	0.00
Krefftichthys anderssoni			0.01	0.00	0.01	0.00
Protomyctophum bolini			0.02	0.00		
Notosudidae						
Scopelosaurus hamiltoni					0.05	0.00
Paralepididae						
Magnisudis prionosa					0.46	0.00
Notolepis coatsi	0.01	0.00				
Scopelarchidae						
Benthalbella elongata	0.08	0.00				
Total	7 420.15	100	3 130.94	100	16 167.53	100

1 A study of members of the genus *Pogonophryne* is currently under way.
2 The taxonomy of the genus *Muraenolepis* is unclear (Chiu and Markle, 1990; Kompowski and Rojas, 1993).

Table 2: Parameters of the allometric relationship of length and weight for channichthyids, nototheniids and myctophids in the southern Scotia Arc region. E – Elephand Island, SO – South Orkney Islands, SS – South Shetland Islands.

Species	Area	*a*	*b*	Number Measured	Length Range (cm)	*R2*	Reference
Channichthyidae							
Chaenocephalus aceratus	SS	0.00050	3.67217	202	14.5–71.5	0.9930	This paper
	E	0.00027	3.83510	206	17.5–70.5	0.9876	This paper
	E	0.00045	3.70539	725	13.5–61.5	0.9900	Kock, 1986
	SO	0.00012	4.04845	516	14.5–70.5	0.9747	This paper
Cryodraco antarcticus	SO	0.00062	3.52239	181	20.5–45.5	0.9173	This paper
Champsocephalus gunnari	SS	0.00056	3.70446	166	20–48	0.9853	This paper
	SS	0.00160	3.34000	185	11.7–44.5	0.9900	Balguerías & Quintero, 1989
	E	0.00080	3.58100	290	12.5–51.5	0.9889	This paper
	E	0.00154	3.38210	594	11–46	0.9900	Kock, 1986
	E	0.00099	3.51000	185	10.5–51.2	0.9900	Balguerías & Quintero, 1989
	SO	0.00169	3.42108	530	12.5–51.5	0.9649	This paper
	SO	0.00067	3.59000	253	9.8–51.2	0.9700	Balguerías & Quintero, 1989
Chionodraco rastrospinosus	SS	0.00039	3.85572	346	25.5–45.5	0.9158	This paper
	E	0.00028	3.94831	167	29.5–46.5	0.9203	This paper
	SO	0.00077	3.68221	321	16.5–48.5	0.9625	This paper
Pseudochaenichthys georgianus	SS	0.00120	3.56850	64	18.5–55.5	0.9903	This paper
	SS	0.01200	2.72000	70	8.4–18.7	0.9800	Balguerías & Quintero, 1989
	SO	0.00052	3.70614	212	27.5–53.5	0.9695	This paper
	SO	0.00080	3.65000	122	16.0–52.6	0.9900	Balguerías & Quintero, 1989
Nototheniidae							
Gobionotothen gibberifrons	SS	0.00206	3.43535	160	22.5–40.5	0.9618	This paper
	SS	0.00110	3.62000	585	12.6–49.8	0.9900	Balguerías & Quintero, 1989
	E	0.00223	3.43885	203	22.5–48.5	0.9702	This paper
	E	0.00177	3.49110	657	12.0–44.0	0.9900	Kock, 1986
	E	0.00096	3.66000	891	14.3–46.2	0.9800	Balguerías & Quintero, 1989
	SO	0.00083	3.70249	368	10.5–46.5	0.9807	This paper
	SO	0.00085	3.65000	510	9.8–51.2	0.9900	Balguerías & Quintero, 1989
Lepidonotothen larseni	SO	0.00417	3.24056	222	9.5–23.5		This paper
Lepidonotothen squamifrons	SS	0.00233	3.44440	116	15.5–45.5	0.9834	This paper
	E	0.00230	3.45856	94	15.5–47.5	0.9760	This paper
	SO	0.00334	3.36261	339	9.5–49.5		This paper
Notothenia coriiceps	SS	0.00746	3.23741	106	34.5–52.5	0.9093	This paper
	E	0.03583	2.81959	57	33.5–54.5	0.9206	This paper
	SO	0.01933	2.98645	32	33.5–48.5	0.9125	This paper
Notothenia rossii	E	0.00741	3.19440	713	31.5–68.5	0.9700	Kock, 1986
	E	0.00400	3.30000	108	36.5–58.3	0.9500	Balguerías & Quintero, 1989
	SO	0.00819	3.16037	157	37.5–66.5	0.9384	This paper
Trematomus eulepidotus	SO	0.00209	3.58287	146	15.5–34.5		This paper
Trematomus hansoni	SO	0.00138	3.63149	51	16.5–45.5		This paper
Trematomus newnesi	SO	0.00012	4.04895	24	14.5–24.5		This paper
Electrona antarctica	SO	0.20425	1.96179	199	6.5–10.5		This paper
Gymnoscopelus nicholsi	SO	0.04717	2.47241	124	12.5–18.5		This paper

Table 3: Estimates of length (cm) at which 50% of the population has developed beyond the immature stage (L_{50}) and the mature stage (L_{m50}), for fish collected around Elephant Island and the lower South Shetland Islands in 1998 and around the South Orkney Islands in 1999.

Species	Sex	South Orkney Islands			Elephant Island			South Shetland Islands		
		n	L_{50}	L_{m50}	*n*	L_{50}	L_{m50}	*n*	L_{50}	L_{m50}
Chaenocephalus aceratus	F	1 290	49.0	57.6	172	49.5	57.2	193	47.7	58.3
	M	895	36.1	44.0	108	39.5	44.6	202	38.2	46.9
Chaenocephalus aceratus (Kock, 1986, 1989a)	F	473	48.4	-	3 300	45.6	57.1	-	-	-
	M	425	40.5	-	1 358	41.1	45.7	-	-	-
Champsocephalus gunnari	F	360	29.5	35.3	910	31.4	44.8	777	31.3	37.7
	M	452	33.8	39.1	728	32.0	46.2	770	32.1	35.6
Chionodraco rastrospinosus	F	1 458	34.0	36.7	177	34.9	39.6	182	34.4	38.9
	M	1 836	32.9	35.6	66	36.5	37.6	206	34.4	36.4
Chionodraco rastrospinosus (Kock, 1989a)	F	-	-	-	466	31.3	36.7	-	-	-
	M	-	-	-	487	32.7	33.3	-	-	-
Pseudochaenichthys georgianus	F	935	38.4	45.6	-	-	-	-	-	-
	M	974	38.1	45.1	-	-	-	-	-	-
Gobionotothen gibberifrons	F	7 730	32.0	34.6	2 943	36.0	39.5	717	33.4	39.0
	M	7 152	30.0	33.0	4 404	30.1	36.4	740	30.7	33.7
Gobionotothen gibberifrons (Kock, 1989a)	F	-	-	-	12 646	36.4	38.6	-	-	-
	M	-	-	-	13 564	35.4	35.9	-	-	-
Lepidonotothen larseni	F	511	14.4	16.9	-	-	-	-	-	-
	M	219	17.3	22.5	-	-	-	-	-	-
Lepidonotothen squamifrons	F	3 172	32.6	36.8	-	-	-	251	30.5	32.4
	M	2 588	34.8	-	-	-	-	209	29.4	-
Notothenia rossii	F	66	47.6	51.9	-	-	-	-	-	-
	M	86	-	42.5	-	-	-	-	-	-
Notothenia rossii (Kock, 1989a)	F	-	-	-	140	49.9	52.6	-	-	-
	M	-	-	-	872	42.2	45.2	-	-	-
Trematomus eulepidotus	F	111	27.5	27.8	-	-	-	-	-	-
	M	101	22.4	22.4	-	-	-	-	-	-

Table 4: Mean gonadosomatic index, minimum, maximum and variance of females and males of several channichthyids, nototheniids and *Muraenolepis microps* in the southern Scotia Arc region in March 1998 and March 1999. E – Elephand Island, SO – South Orkney Islands, SS – South Shetland Islands.

Species	Area	Sex	*n*	Mean	Min.	Max.	Variance
Channichthyidae							
Chaenocephalus aceratus	SS	F	2	15.02	10.26	14.87	-
	SO	F	71	14.3	2.06	25.35	20.93
		M	17	1.93	0.84	2.70	0.23
Champsocephalus gunnari	SS	F	6	15.02	9.74	22.27	4.79
	SO	F	224	6.52	0.93	11.29	3.91
		M	212	2.29	0.28	6.45	0.45
Chionodraco rastrospinosus	SS	F	10	24.66	20.96	28.64	3.29
	SO	F	70	20.22	11.76	25.94	9.59
		M	8	3.96	1.67	16.00	24.00
Nototheniidae							
Gobionotothen gibberifrons	SO	F	2	7.48	5.97	8.99	4.56
Lepidonotothen larseni	SO	F	4	7.26	5.13	11.54	8.48
Lepidonotothen nudifrons	SS	F	2	17.19	15.38	20.00	-
	SO	F	6	17.15	10.87	23.81	35.62
Lepidonotothen squamifrons	SO	F	1	8.20			
Notothenia coriiceps	SS	F	2	10.11	9.22	11.02	-
	SO	F	7	9.38	6.95	13.05	2.20
		M	14	9.22	2.58	14.26	3.15
Notothenia rossii	SO	F	9	12.50	4.22	19.38	26.65
		M	17	9.06	2.21	22.55	37.62
Pseudochaenichthys georgianus	SO	F	38	8.12	4.07	18.56	7.09
		M	23	1.26	0.53	2.00	0.09
Trematomus bernacchii	SO	F	2	3.90	3.21	4.59	0.95
Trematomus eulepidotus	SO	F	36	18.84	10.00	27.78	17.40
		M	29	6.14	3.70	10.56	2.41
Trematomus hansoni	SO	F	6	9.65	2.20	24.88	108.66
Trematomus newnesi	SO	F	6	11.25	9.09	14.00	5.41
Muraenolepidae							
Muraenolepis microps	SS	F	1	8.55	-	-	-
	SO	F	1	10.13	-	-	-

Table 5: Egg diameter (fresh), gonadosomatic index and estimated time of spawning in 14 species of Antarctic nototheniids and channichthyids found at the South Orkney Islands. SO – South Orkney Islands, SS – South Shetland Islands.

Species	Area	Length Range (cm)	*n*	Gonado-somatic Index	Egg Diameter (mm)	Estimated Egg Diameter at Spawning (mm)	Estimated Spawning Time
Channichthyidae							
Chaenocephalus aceratus	SS	58–63	2	10.3–14.9	3.28–3.73	4.6–4.9	May–June
	SO	52–70	24	3.2–25.4	1.60–4.51	4.6–4.9	April–June
Champsocephalus gunnari	SS	29–44	6	9.8–22.2	2.52–3.36	3.5–3.8	April–June
	SO	40–52	10	5.5–9.5	1.71–2.29	3.5–3.8	July–August
Chionodraco rastrospinosus	SS	36–44	6	20.9–28.6	4.37–5.33	4.3–5.3	March–May
	SO	32–48	15	16.9–23.7	3.82–4.53	4.7–5.3	April–May
Pseudochaenichthys georgianus	SO	45–51	10	5.4–10.6	1.92–2.98	4.4–4.9	June–July
Nototheniidae							
Gobionotothen gibberifrons	SO	35–46	11	5.4–9.0	0.74–0.94	1.8–2.0	August–September
Lepidonotothen larseni	SO	17–20	5	5.1–9.4	0.86–0.97	1.8–2.2	August–September
Lepidonotothen nudifrons	SS	13–17	2	15.4–20.0	1.94–2.05	2.5	April–June
	SO	14–19	9	12.3–17.0	1.61–1.87	2.5	May–June
Lepidonotothen squamifrons	SS	33	1	11.2	1.15	1.2–1.4	February–March
	SO	37–42	4	8.2	0.83	1.2–1.4	February–March
Notothenia coriiceps	SS	42–46	2	9.2–11.0	2.55–2.70	4.4–4.7	May–June
	SO	39–48	4	7.9–13.1	1.77–2.13	4.4–4.7	May–June
Notothenia rossii	SO	51–65	10	11.3–14.0	2.54–3.01	4.8–5.2	May–June
Trematomus bernacchii	SO	37	1	8.6	1.23	4.4–4.6	October
Trematomus eulepidotus	SO	27–34	13	(10.6) 17.0–23.6	(1.66) 1.63–2.16	2.8–3.0*	April–May
Trematomus hansoni	SO	45	2	21.0–24.8	2.77–2.85	2.7–2.9	February–March
Trematomus newnesi	SO	16–21	6	9.1–13.5	1.20–1.54	?	June–July

* Measured from a few residual eggs.

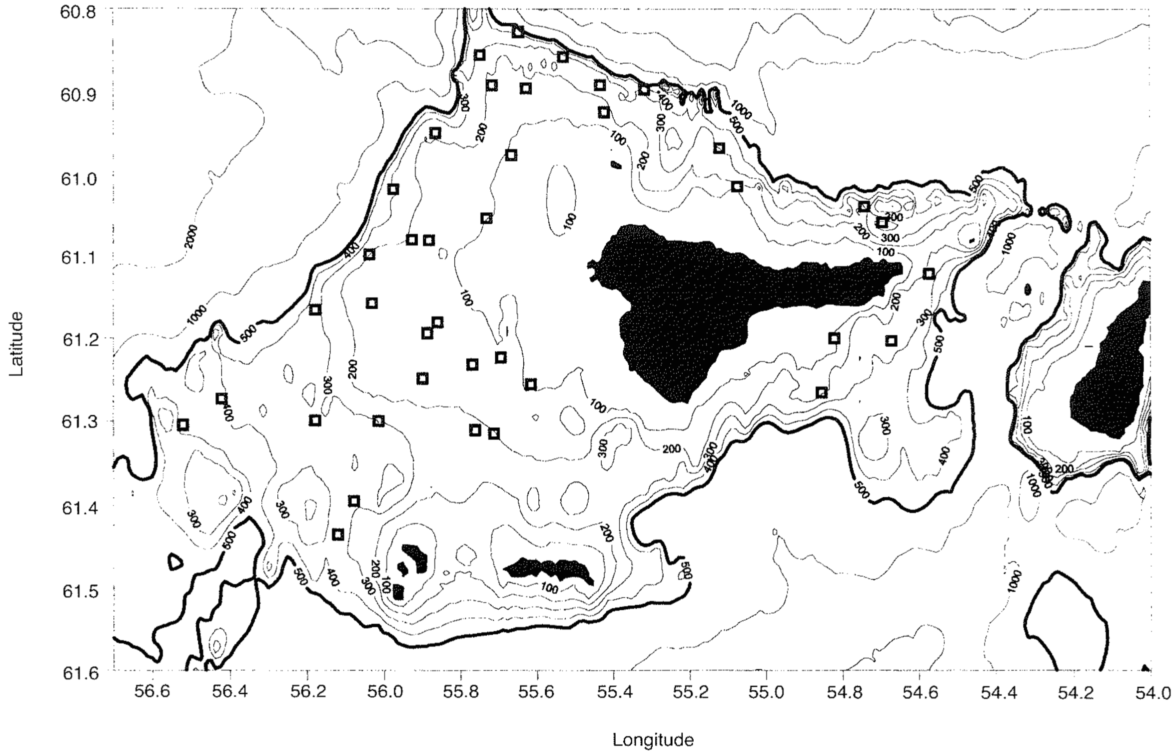


Figure 1a: Location of fishing stations around Elephant Island in March 1998.

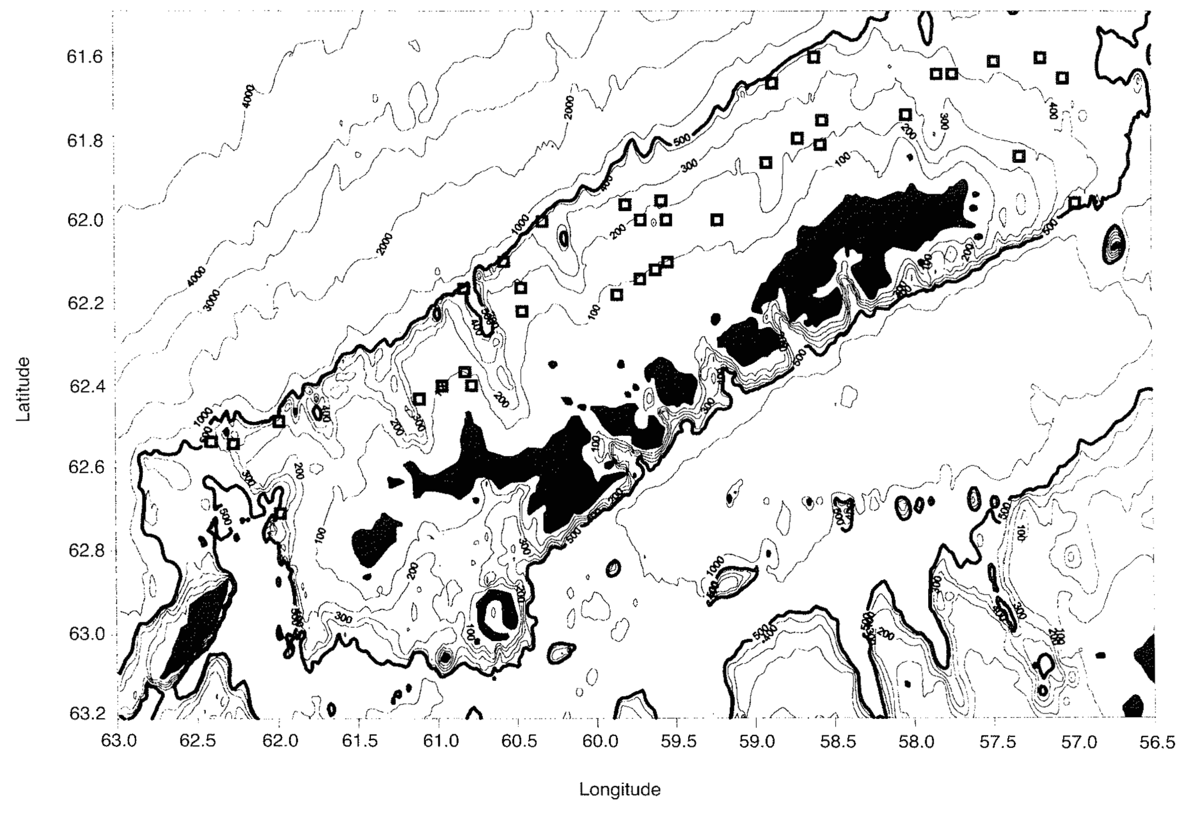


Figure 1b: Location of fishing stations around the South Shetland Islands in March 1998.

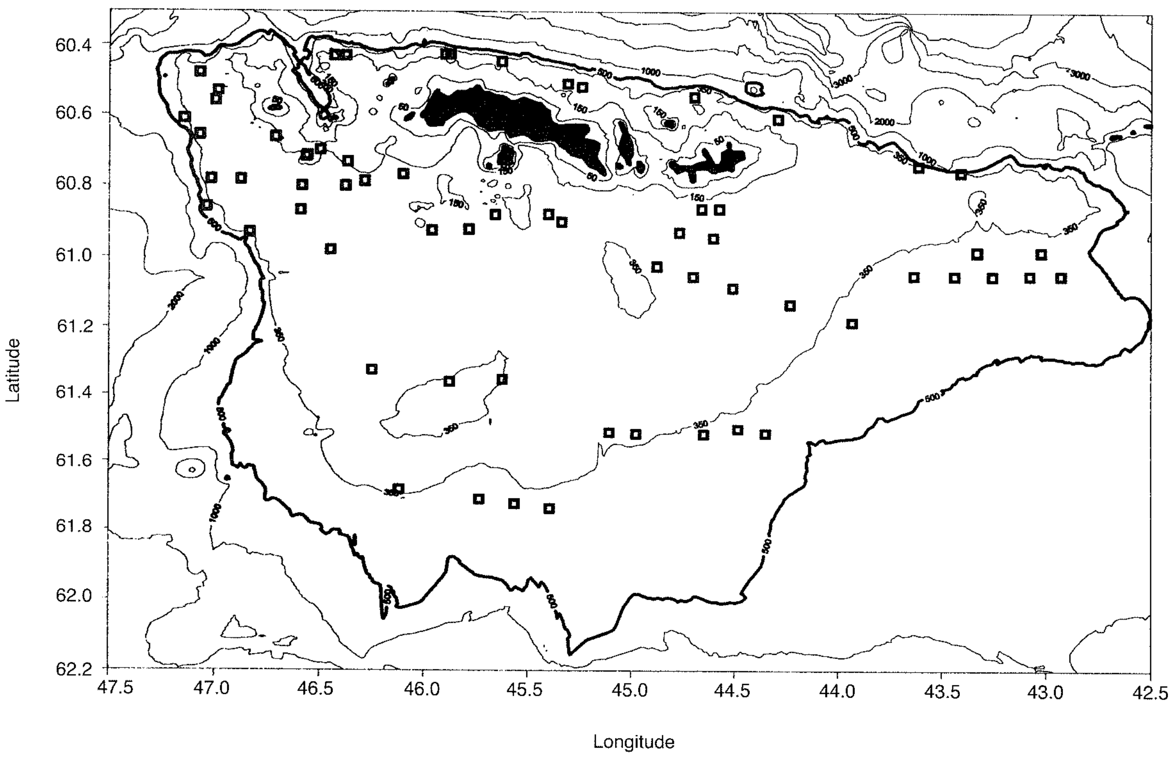


Figure 1c: Location of fishing stations around the South Orkney Islands in March 1999.

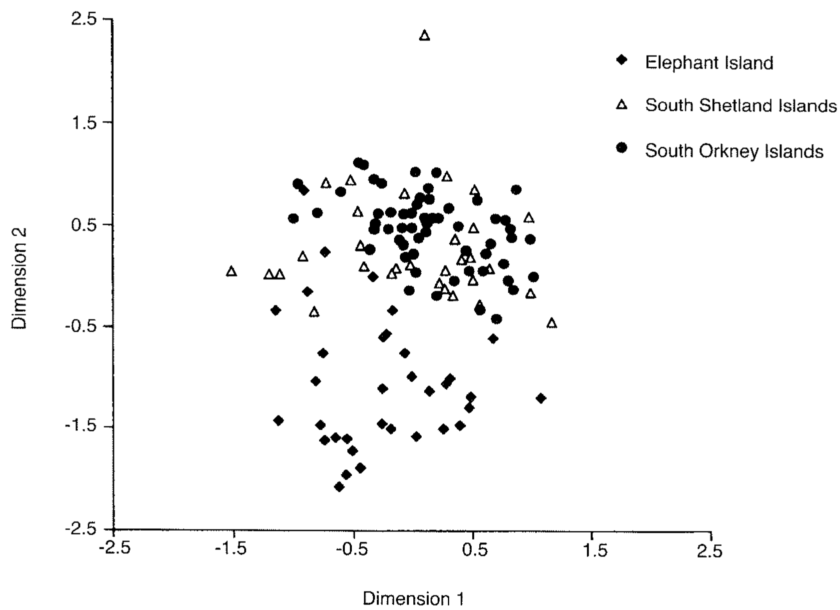
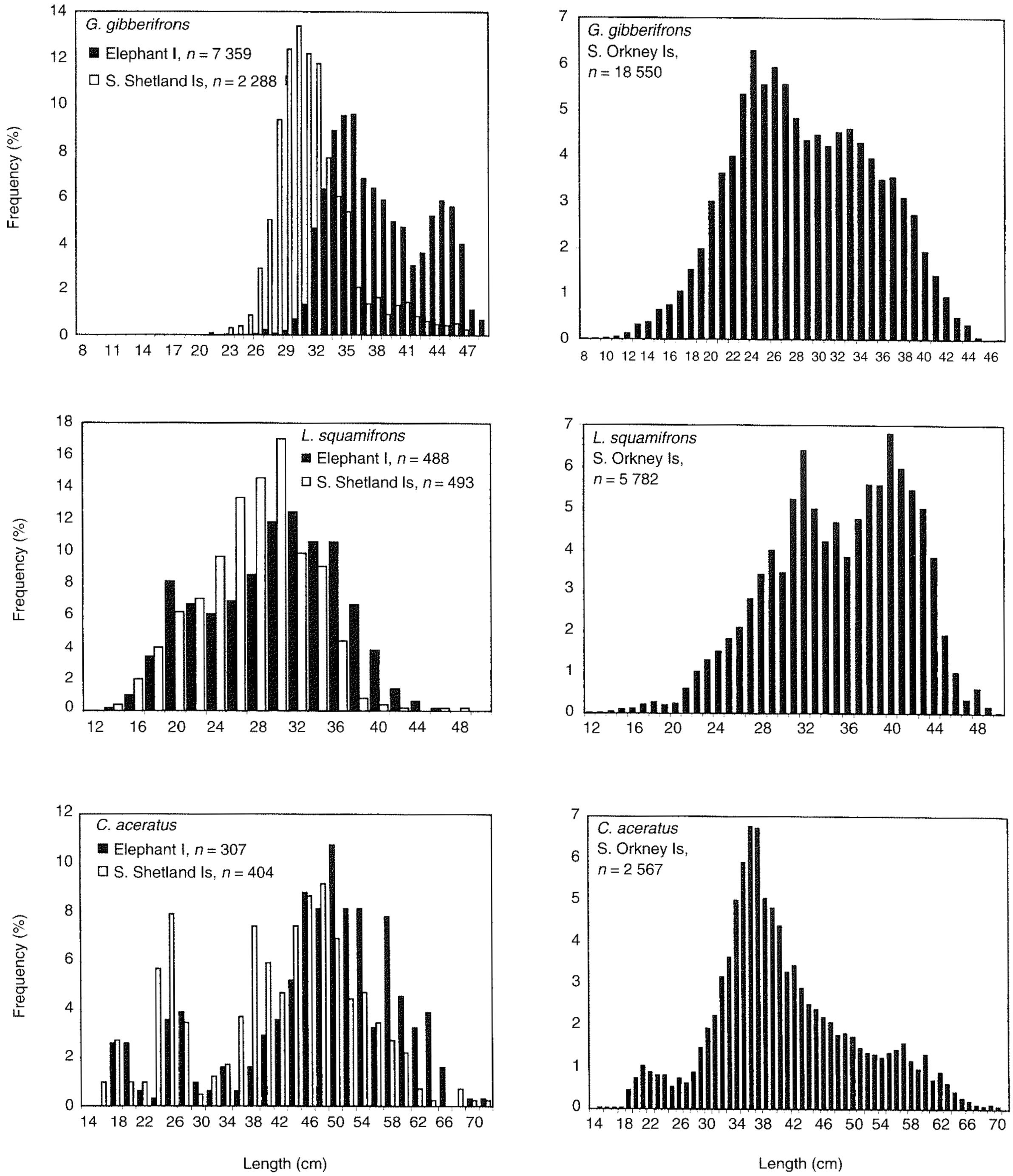


Figure 2: MDS plot of species similarities in the three study areas.



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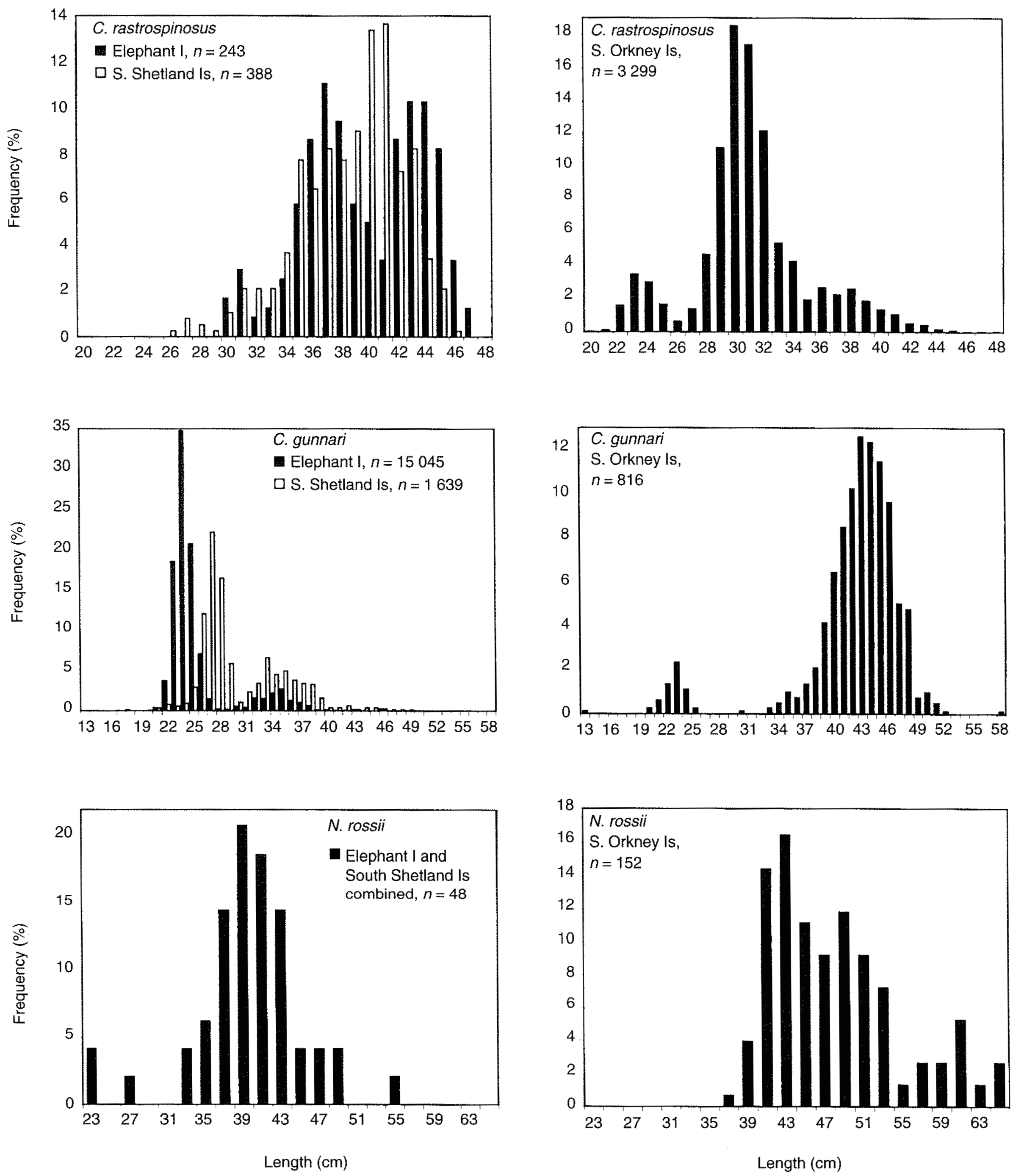

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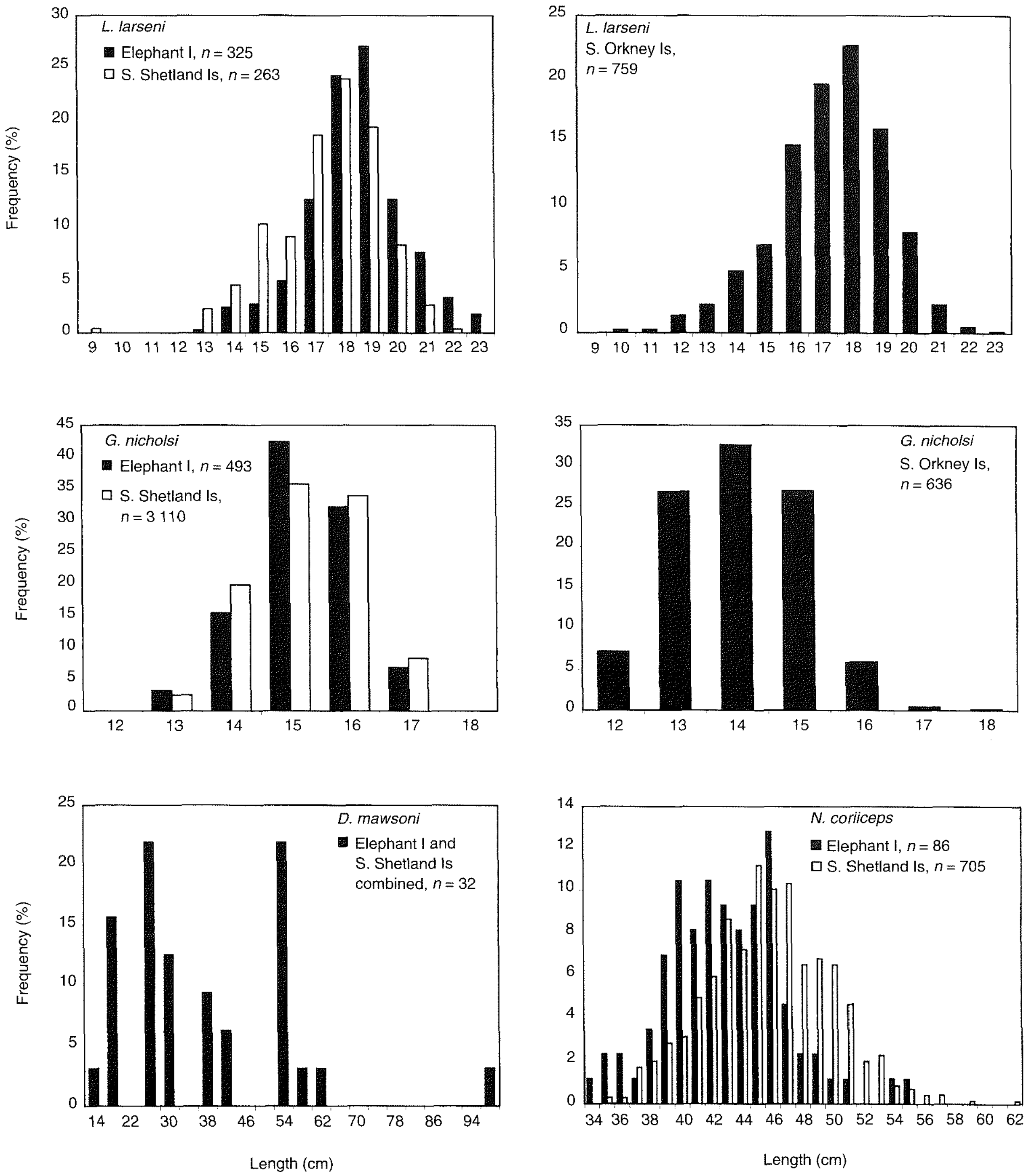

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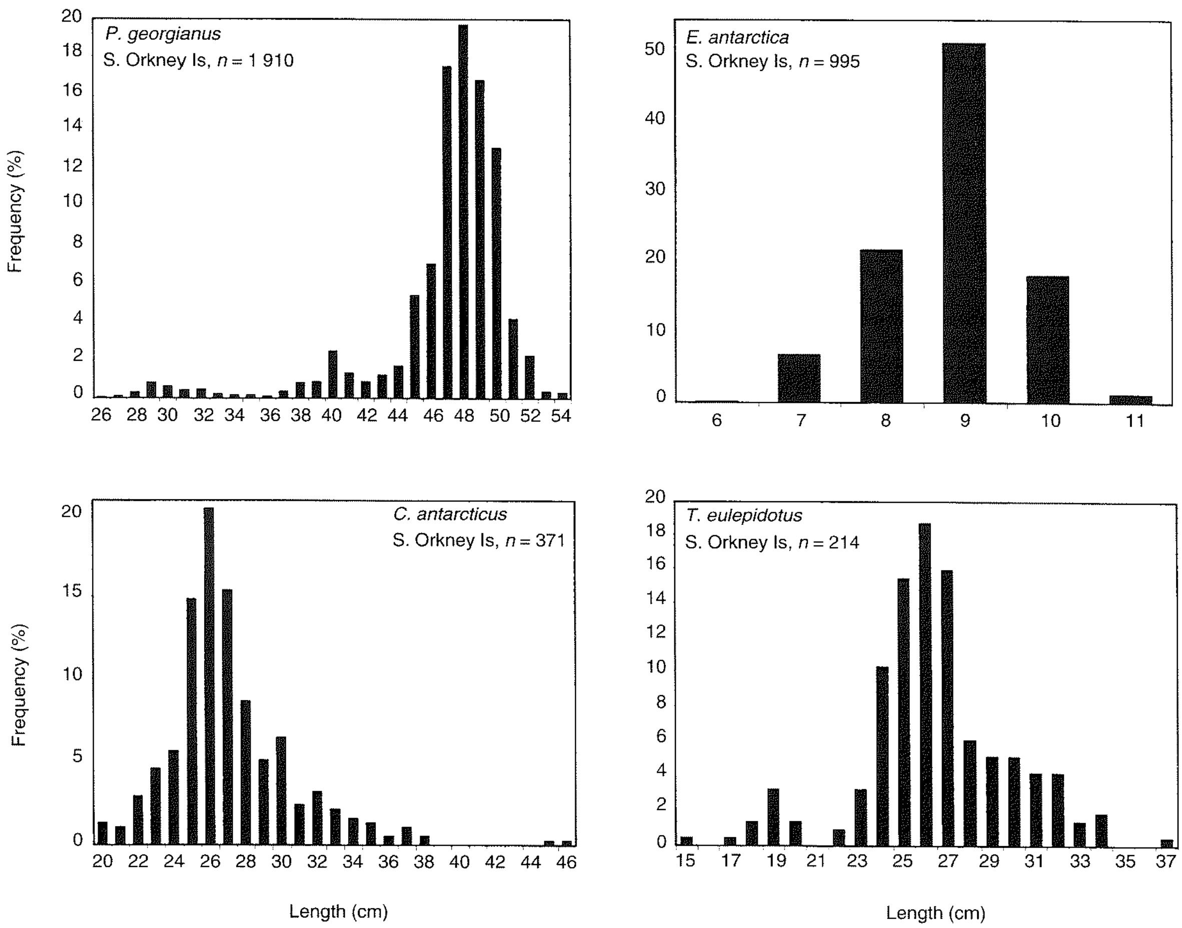

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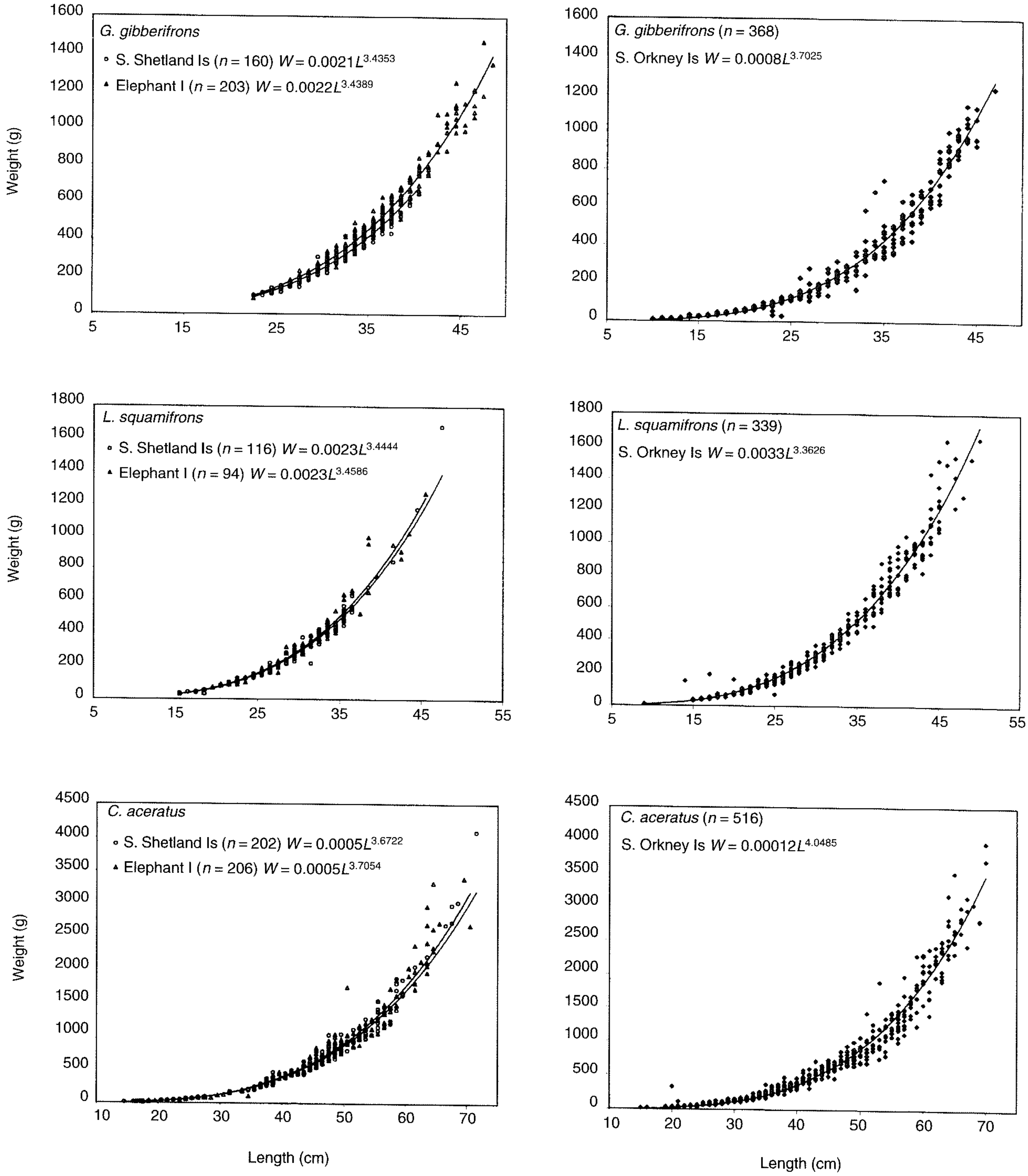

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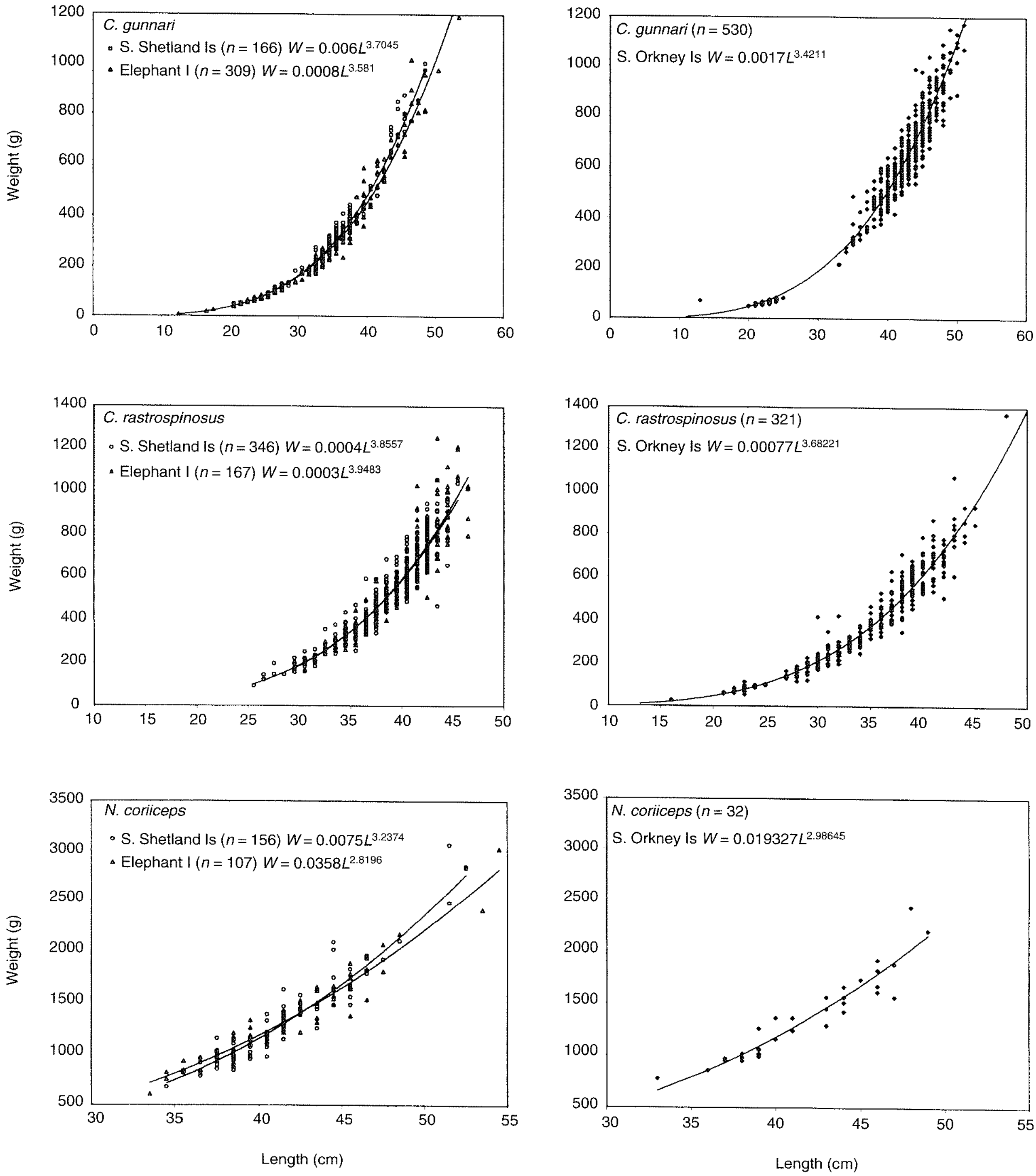

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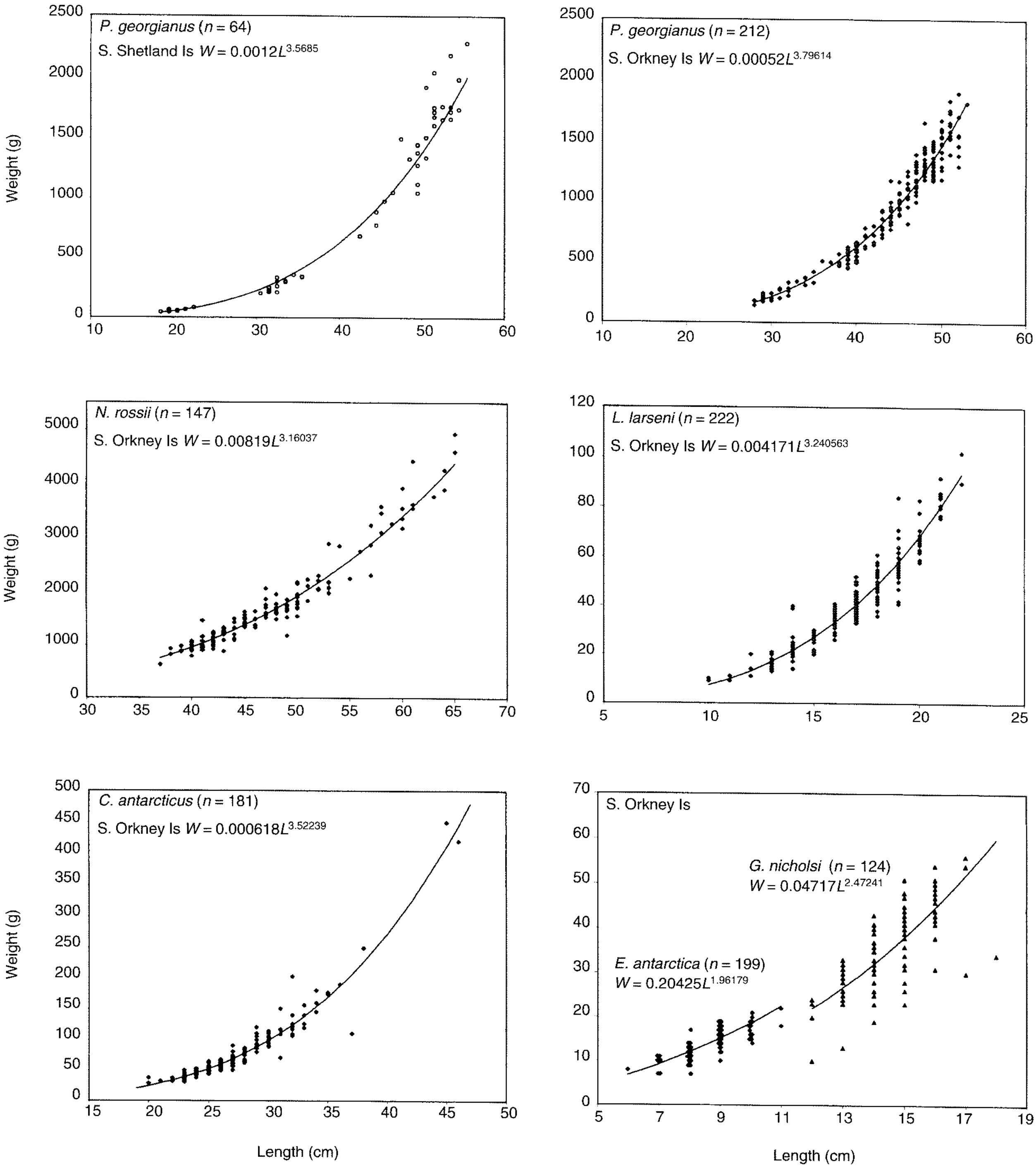

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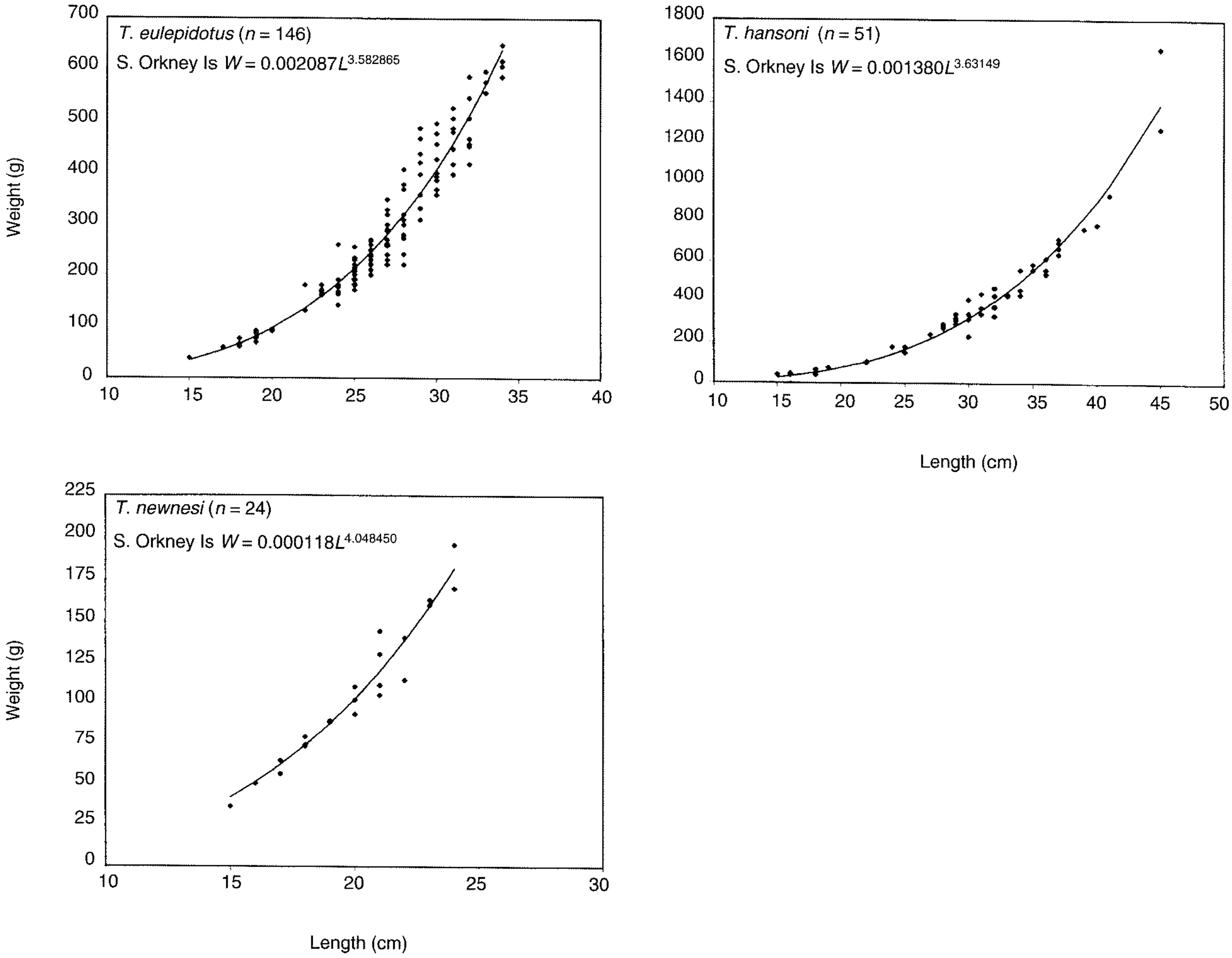

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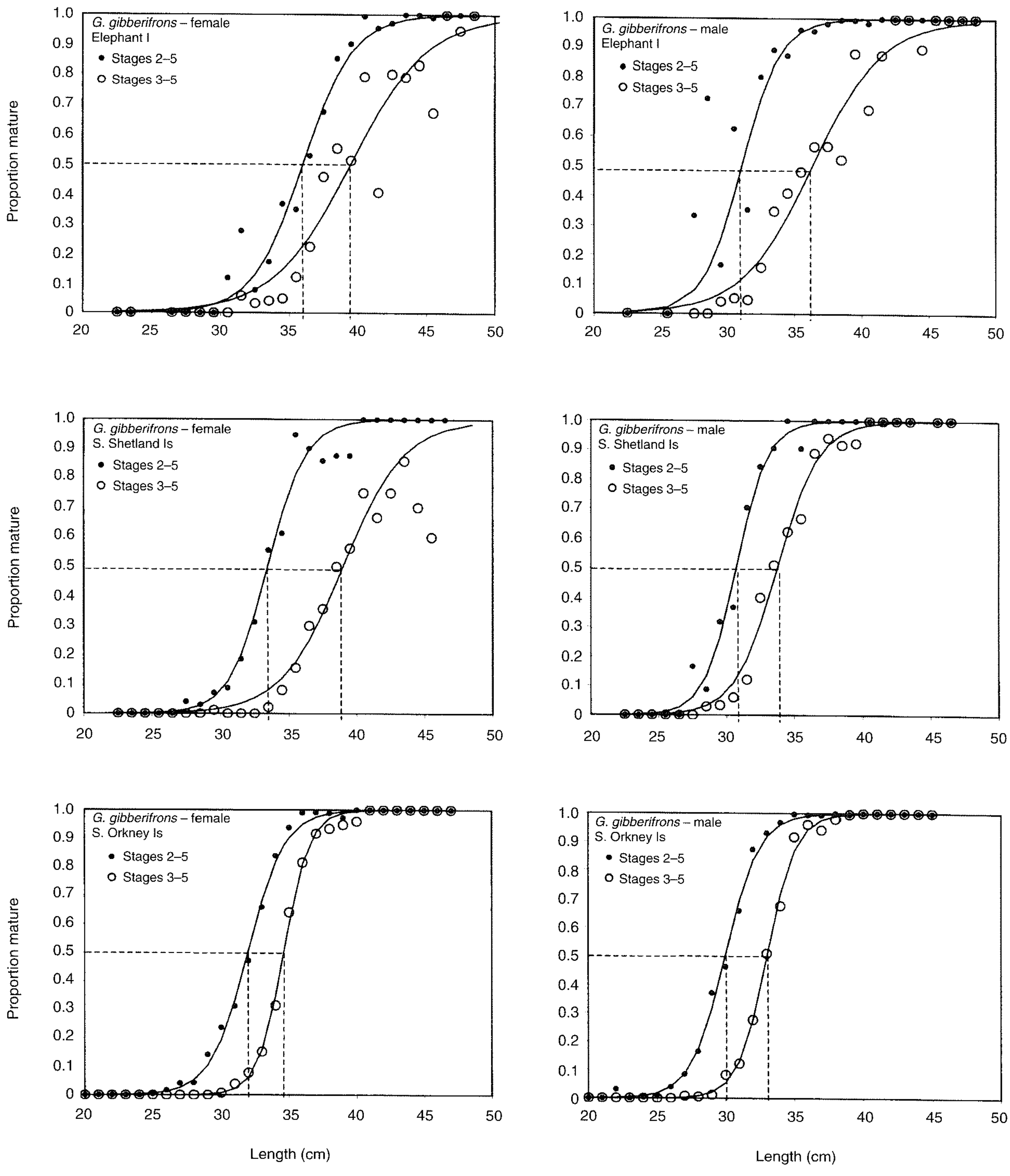

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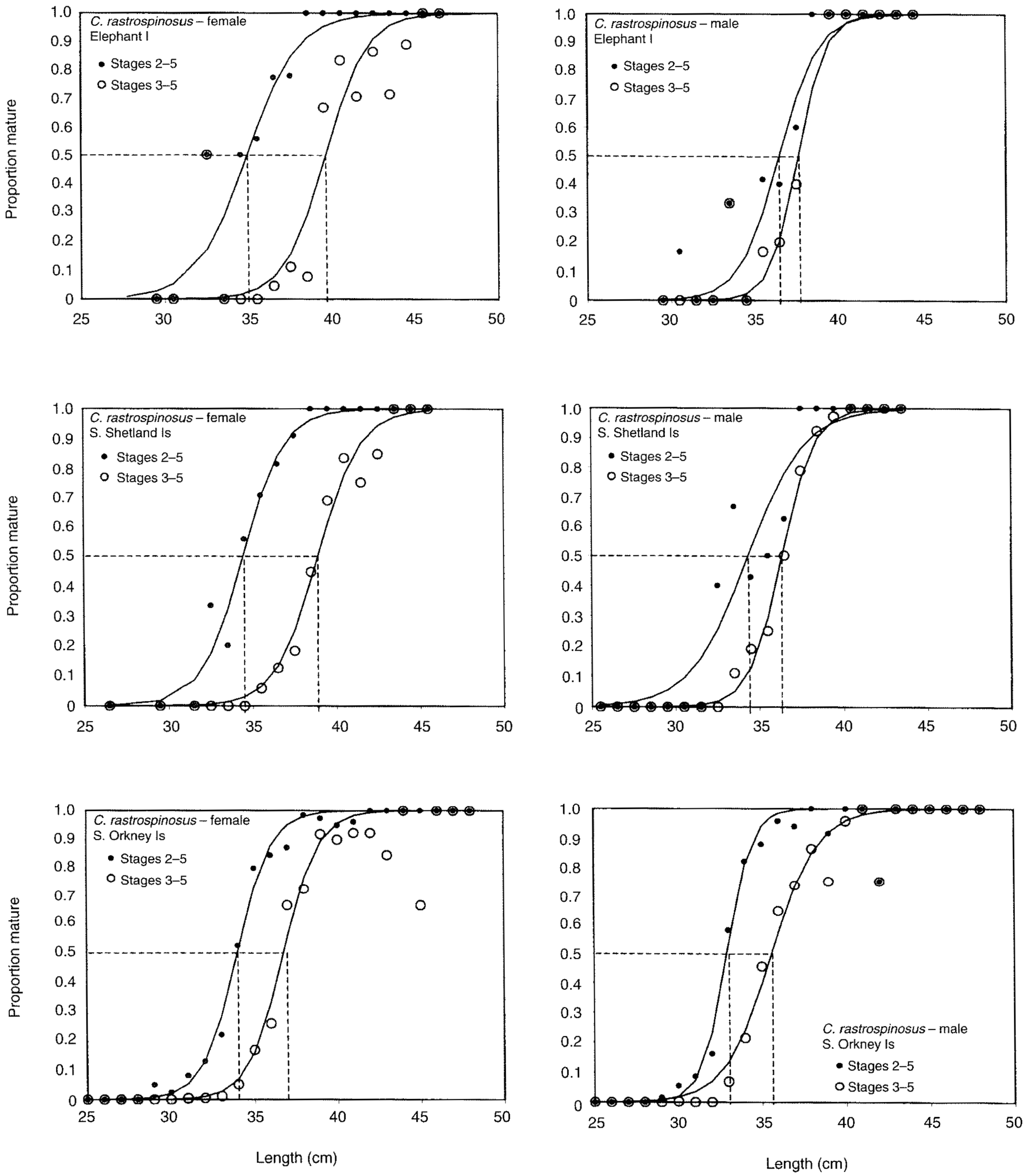

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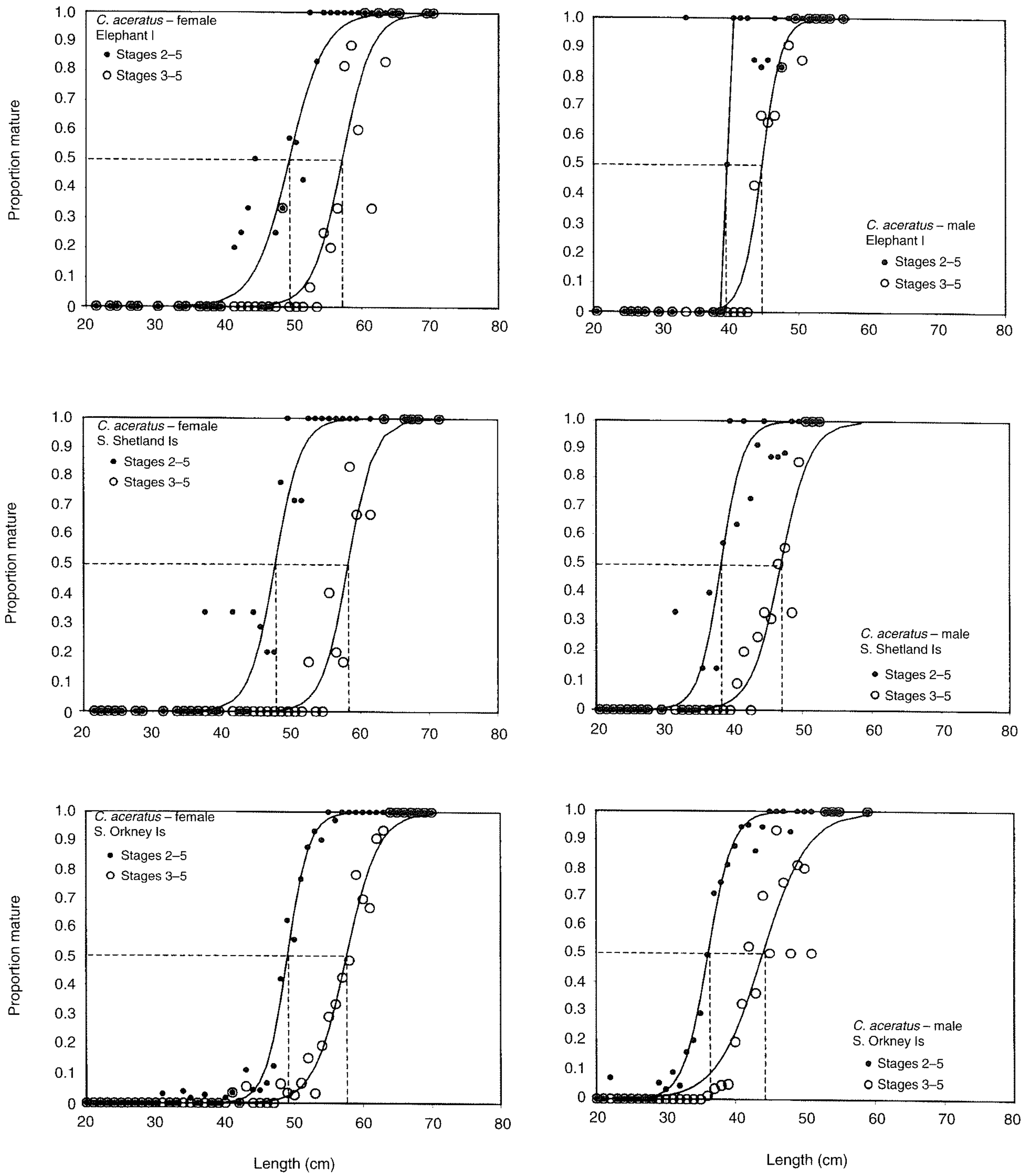

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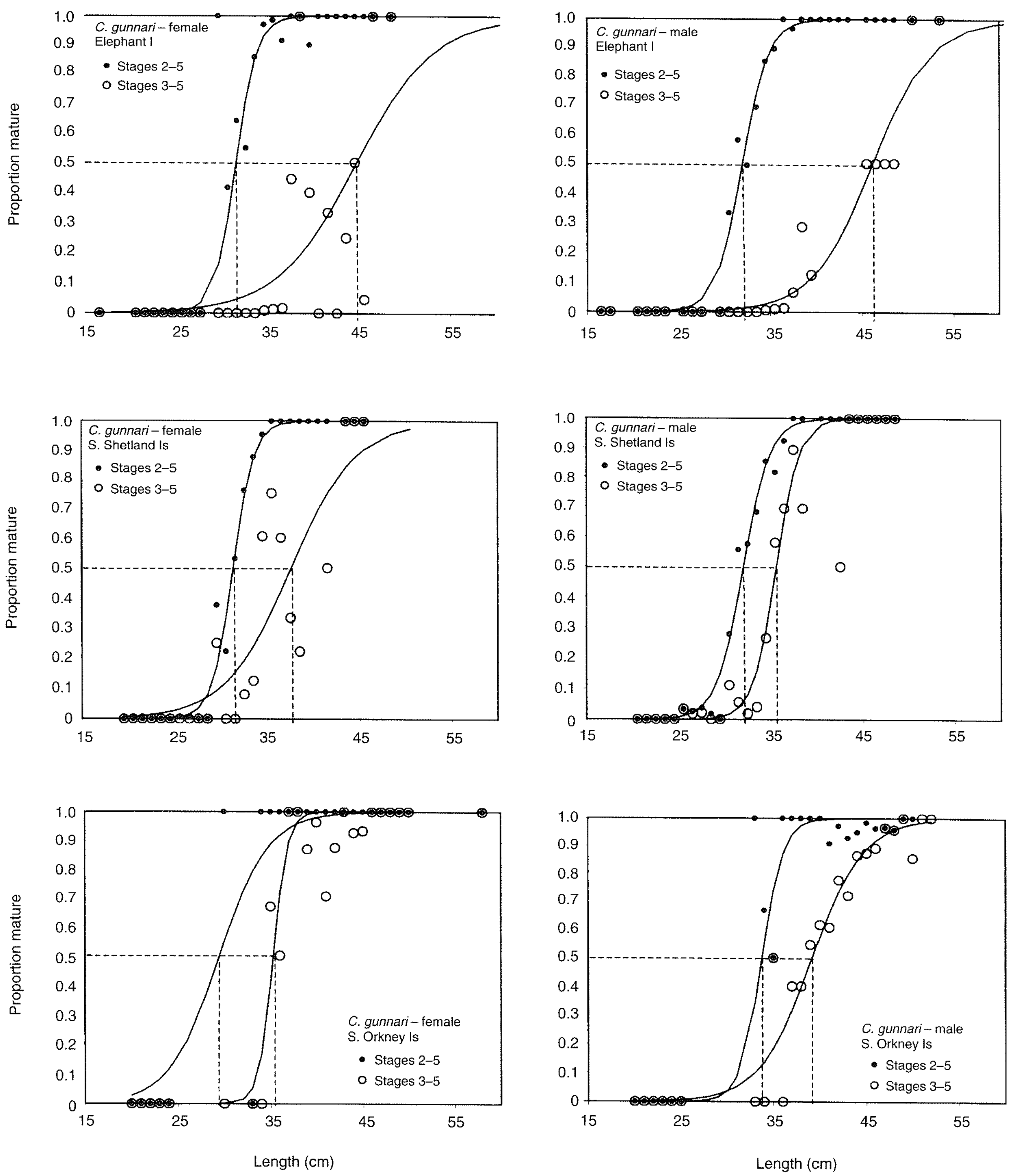

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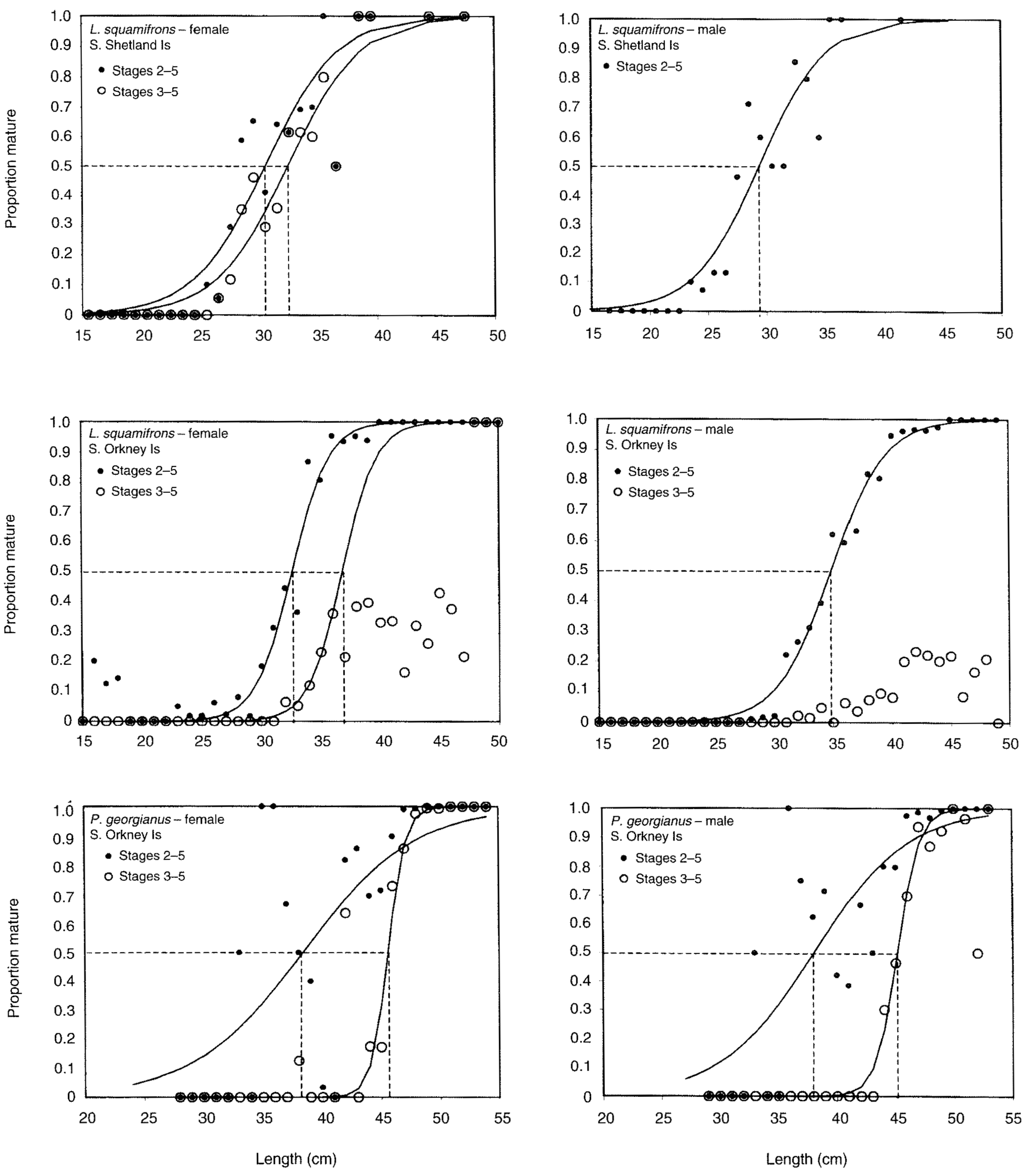

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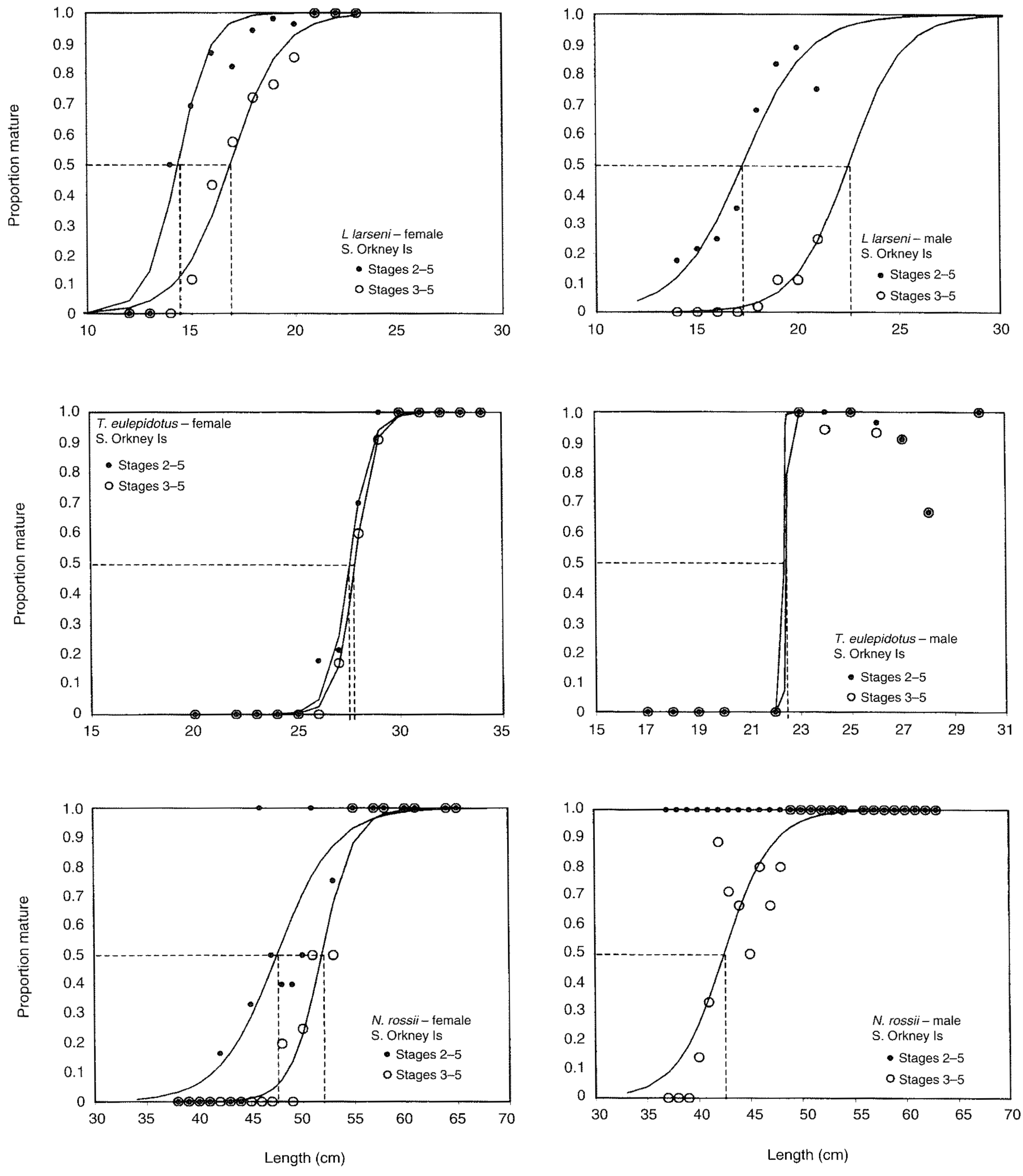

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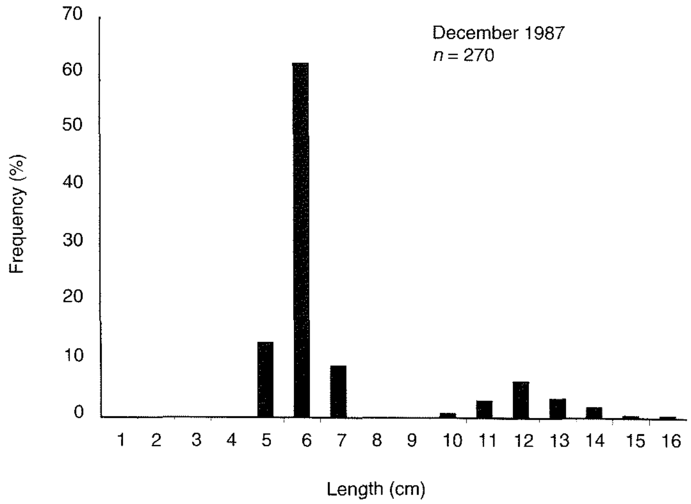

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