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Standardization of time series for the EU bottom trawl Flemish Cap survey: Estimation of conversion factors between RV Cornide de Saavedra and RV Vizconde de Eza

Alfonso Pérez-Rodriguez (1) and Mariano Koen-Alonso (2)

(1) Instituto de Investigaciones Marinas, CSIC, Vigo, Spain

(2) Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada, St. John's, Canada

Abstract:

Catchability of fishes is known to be affected by changes in gear, survey timing, and research platform. In 2003 the RV Cornide de Saavedra was replaced by the RV Vizconde de Eza in the annual EU Flemish Cap survey (NAFO Division 3M); as part of this change, paired fishing tows were carried-out in 2003 and 2004. Although conversion factors were developed for some commercial species, there is also a need of conversion factors for non-commercial species. The goal of this study was to develop these factors for all fish species, as well as *Pandalus borealis* and *Illex illecebrosus*. When sample sizes were too small, conversion factors were evaluated for operational groups defined by general body shape and species habitat. Relative fishing efficiency between vessels was analyzed using fixed effects conditional distribution models with and without fish size as covariate. Results indicated that RV Vizconde de Eza had a significantly higher fishing efficiency than RV Cornide de Saavedra. However, only *Pandalus borealis* and *Illex illecebrosus* presented size-dependent differences in fishing efficiency, with a remarkably greater catchability for RV Vizconde de Eza at smaller sizes. These differences may be explained by differences in gear characteristics and winch-related equipment and operation between the vessels. Conversion factors for key commercial species obtained in this study were higher than those found in previous analyses.

Introduction

Catchability of organisms is known to be affected by survey timing, area sampled, time of day in which fishing takes place, as well as the research vessel and gear used (Warren 1997; Pelletier 1998; Benoît and Swain 2003a). Basic survey data needs to be corrected for variations in these factors to avoid changes in catchability owed to them to be incorrectly interpreted as changes in resource abundance. In the concrete case of research vessel change, a calibration process is needed if continuity of the time series wants to be maintained (Pelletier 1998).

In the Flemish Cap area (NAFO Division 3M), a summer (June-July) random stratified bottom trawl survey has been annually conducted since 1988 (Vázquez 1998). In 2002, this survey became part of the Spanish and Portuguese programs supported by the European Union (EU) Common Fishery Policy. Participating institutions have been the Spanish Institute of Oceanography (IEO), the Institute of Marine Research (IIM-CSIC) and the Technological Fishery and Alimentary Institute (AZTI-Tecnalia) from Spain, and the Institute of Fisheries and Sea Research (IPIMAR) from Portugal. These surveys have provided time series of abundance, size composition, and distribution for over 70 fish species. These datasets constitute the basic source of information for stock-assessments of both commercial and non-commercial species in the Flemish Cap.

RV Cornide de Saavedra was the standard research platform assigned to the Flemish Cap survey. This changed in 2003 when this vessel was replaced by the RV Vizconde de Eza. The reason behind this change was the need for improving survey coverage at depths beyond the operational capacity of RV Cornide de Saavedra. To evaluate the influence of the different characteristics of these two research platforms on fish catchability, a calibration process was deemed necessary. Hence, comparative fishing exercises (i.e. paired fishing between the two vessels) were done during the 2003 and 2004 Flemish Cap surveys. These comparative trawls were used to estimate conversion factors to scale the data series of key commercial species from its original RV Cornide de Saavedra values to RV Vizconde de Eza equivalents. González-Troncoso and Casas (2005) estimated conversion factors for the main fish species, *Gadus morhua*, *Reinhardtius hippoglossoides*, *Hippoglossoides platessoides*, *Sebastes* sp. and *Macrourus berglax*, while Casas *et al*. (2004) did it for *Pandalus borealis*.

Since conversion factors are only available for key commercial species, an essential pre-requisite for any study of trends and dynamics of the Flemish Cap at the marine community/ecosystem level is the development of conversion factors for [ideally] all species in the survey. Furthermore, to ensure a common footing in the treatment of the data between commercial and non-commercial species, conversions factors should be derived from a consistent set of analyses, assumptions, and considerations. The present study is aimed to develop such conversion factors for all fish species, as well as invertebrates *Pandalus borealis* and *Illex illecebrosus*.

Material and Methods

Comparative fishing sets between RV Cornide de Saavedra and RV Vizconde de Eza were carried out from 7th to 17th June 2003 and from 23th July to 2nd August 2004. The distance between both vessels was always between 0.25 and 0.5 miles, depending on weather conditions, and the relative position of the vessels (port or starboard) was varying. The target set duration was 30 minute at 3.5 knots, but sets with more than 20 minutes duration were also considered valid for the comparative fishing exercise.

A total of 54 and 69 paired fishing sets were conducted in 2003 and 2004 respectively. Although both vessels used the same fishing gear (Lofoten trawl with a 35 mm codend mesh size), during the first 51 paired sets of 2003 the RV Vizconde de Eza also used a 17-20 mm mesh size codend cover. Previous calibration studies (González-Troncoso and Casas 2005, Casas et al 2004) assumed that, among the species of interest, this difference only affected *Pandalus borealis* and juvenile redfishes (Casas and González, 2003). Data for these species were converted to their estimated equivalent without codend cover before being used for comparative fishing analyses (Casas and González, 2003). A more conservative approach was taken in this study. All 51 sets where the codend cover was used were excluded from the analysis, leaving only 3 paired sets for consideration from 2003. From the 69 paired sets done in 2004, 8 suffered significant gear damage, leaving 61 valid paired sets for further analysis (Table 1).

Differences in tow distance between paired fishing sets are possible due to variations in actual speed between vessels or the encounter by one of the vessel of bottom conditions that make unadvisable continuing trawling. Those paired fishing sets for which differences in covered distance was greater than 20% were considered invalid. As a result, one set from 2003 and four from 2004 were also excluded from the analysis (Table 1).

After all the above considerations, a total of 59 paired fishing sets (2 from 2003 and 57 from 2004) were considered valid and used for the analysis. For these valid sets, the mean difference in towed distance was 4.45%. To correct for these differences catches were standardized assuming a linear relationship between catch and distance towed.

For each species, outliers were identified by examining the difference in the number of individuals caught between vessels in a paired set. By considering this difference as a random variable, the Tchebychev’s inequality was employed to approximate the interval which contains these differences with a probability of 0.88. All observed differences outside these intervals were considered outliers and the corresponding paired fishing set excluded from the analysis for that particular species. When fish length was included as covariate in the analysis, outliers were identified in the same way, but differences in numbers caught between vessels were calculated by size class (i.e. if in a given set, a size class difference was identified as an outlier, the entire fishing set was excluded from analysis).

A fixed effects conditional distribution model (Benoît 2006) was used to evaluate the relative fishing efficiency between RV Cornide de Saavedra and RV Vizconde de Eza. For each species we studied the conditional distribution of RV Vizconde de Eza catches given the total catch obtained by both vessels in the paired fishing set *i*:

$$C_i = C_{iC} + C_{iV}$$

where C_i is the total catch and C_{iC} and C_{iV} are the number of individuals captured in paired fishing i by RV Cornide de Saavedra and RV Vizconde de Eza respectively.

Relative fishing efficiency of RV Vizconde de Eza was evaluated using a generalized linear model, with a logit link and a binomial error distribution (McCullagh and Nelder, 1989). If fishing efficiency of both vessels is equal, the probability of a fish being captured by RV Vizconde de Eza (p_i) is the same that being captured by RV Cornide de Saavedra (1-p_i), then p_i = 1- p_i = 0.5. However, if a difference exists in relative fishing efficiency, 1- p_i must be multiplied by a relative catchability term, b_v, to maintain this equality. This relative catchability term is a function of the estimated intercept parameter of a logistic regression, β_v which is termed the *vessel effect.*

Model 1 $$\ln\left(\frac{p_i}{1-p_i}\right) = \beta_v$$

The relation between the vessel effect β_v and the relative catchability term (b_v) is b_v=exp(β_v)

To study if relative catchability was size-dependent, fish body size was introduced in equation 1 as a covariate. The magnitude of the fish length (*FL*) effect is estimated by the slope (β_1) as:

Model 2 $$\ln\left(\frac{p_{il}}{1-p_{il}}\right) = \beta'_v + \beta_1 FL$$

In this case, this model studies the relative catchability by fish size p_{il}. To maintain the equality p_{il} = 1- p_{il} = 0.5, the relative catchability term, b_v is related to both β_1 and β'_v as b_v=exp($\beta'_v + \beta_1 FL$).

When fitting models for each species, only those paired fishing set in which the focal species was caught at least by one of the vessels were considered. These sets are labelled as relevant sets for that species. In all cases (i.e. models with and without length effects), parameters were estimated by maximum likelihood. Both model 1 and 2 were fitted to all species. Selection of which model to use for calculating conversion factors was dependent on the results obtained for each species.

The assumption of independence embedded in the basic binomial model often underestimates the actual variance in the data. Although extra-binomial models including overdispersion can be used, previous experiences suggest that they do not ensure that all the variance is accounted for in the model, leading to overly liberal tests of nominal statistical significance (Casey and Myers 1998 Benoît and Swain 2003 a,b, Benoît 2006). To overcome this problem the significance of the effects was evaluated using randomization tests (Manly 1991, Benoît, 2006). These tests were built under the null hypothesis of no difference between vessels using the Pearson Chi-square as the statistic for the randomization test. In all cases the empirical distribution of the statistic was obtained using 999 randomizations.

In the case of model 1, with only vessel effect, either C_{iV} or C_{iC} from each relevant set was randomly assigned to the RV Vizconde de Eza, being the other corresponding one allocated to the RV Cornide de Saavedra. A Chi-square statistic was calculated for each one of the 999 iterations. Statistical significance for difference in fishing efficiency between vessels was given by $z=(n+1)/N$, where N is the total number of permutations of the data (including the original result) and n is the number of random permutations that yielded a Chi-square statistic with values equal to or greater than that of the original observed result.

In model 2, following Benoît (2006), the probability of a size-dependent effect was isolated by keeping the vessel effect fixed while only randomizing the fish size effect. This was achieved by keeping the original total catch values observed for each vessel in each paired set, but randomly assigning the size effect. Relative size-frequency distributions were estimated to each vessel in each paired set. One of these distributions was randomly selected and applied to the actual observed catch in the RV Vizconde de Eza, while the remaining relative frequency distribution was applied to the corresponding observed catch in the RV Cornide de Saavedra. In this way, if statistical differences are found, they are only due to differences in the size distributions and not the actual magnitude of the catch. Statistical significance was assessed in a similar way as model 1.

Due to the low number of paired fishing sets available, catches for rare species were so low that made unfeasible the estimation of species-specific calibration factors. To overcome this difficulty, these species were assigned to operational groups and their abundances added up for each paired set. Operational groups were defined based on body shape and habitat characteristics. A total of 17 operational groups, including groups composed by individual species and actual groups, were studied (Table 2).

Results

For each one of the 17 operational groups considered in this study, the number of sets in which they were caught by RV Cornide de Saavedra and RV Vizconde de Eza as well as the total number of relevant paired fishing sets are presented in Table 3. The mean number of relevant sets was 42; minimum and maximum sample sizes were 12 and 58 paired fishing sets which corresponded to operational group 14 and genus *Sebastes* respectively. The number of paired fishing sets classified as outliers was dependent on the model being considered. Hence, the actual number of paired fishing set used for determining the relative fishing efficiency was model-dependent (Tables 5 and 6 respectively).

Figures 1 to 17 summarize the basic data for each operational group considered in this study. In each figure, the left panel provides a scatter plot of the paired catches between fishing vessels for the corresponding relevant sets, and includes the 1:1 line as visual reference. The right panel provides a comparison of the overall relative length frequency distribution for each vessel. For *Glyptocephalus cynoglossus* and the operational group 14, additional graphs magnifying the smaller abundance values are provided (Figures 18 and 19 respectively).

The randomization tests indicated significant vessel effects (i.e. p-values ≤ 0.05) for the following species: *Gadus morhua*, *Illex illecebrosus*, *Urophycis chesteri*, *Reinhardtius hippoglossoides*, *Pandalus borealis*, *Nezumia bairdi*, *Macrurus berglax*, *Lumpenus lumpretaeformis*, *Hippoglossoides platessoides* and *Glyptocephalus cynoglossus*. The operational groups *Lycodes*, *Anarhichas*, group 14, group 16, and group 17 also showed significant vessel effects (Table 4). Although genus *Sebastes* presented a nominally borderline non-significant result (p-value=0.063), for any practical purposes (i.e. use of conversion factor or not) this result can be considered significant. The operational group 15 was the only one that did not show any significant vessel effect.

Pandalus borealis and *Ilex illecebrosus* were the only species that showed significant length-dependent effects in catchability between the two vessels (Table 5). Estimated β'_v values for these species were considerably higher when compared with species without significant size-dependent effects. β_1 was negative in both cases, indicating that RV Vizconde de Eza has a higher fishing efficiency than RV Cornide de Saavedra, but the difference in effectiveness decrease as body size increases. Among fishes, only the genus *Lycodes* showed nearly significant size-dependent effects in catchability (p-value=0.078). All other groups did not show any evidence for this type of effect (Table 5).

Table 6 summarizes the results for those species with significant differences in catchability between the two vessels, or with borderline results that suggest that these effects are present. For species with only vessel effect the percentage of difference on fishing efficiency between vessels ranged between 22.7% for genus *Sebastes* and 114% of *Urophycis chesteri*. For *Pandalus borealis* and *Illex illecebrosus* the relative catchability terms b_vs depend on length. In the case of *Illex illecebrosus*, for a size range of 4 to 20 cm the conversion factor ranged from 20.822 to 1.012. For *Pandalus borealis* a range of 8 - 25 mm of carapace length was associated with a range in conversion factors going from 183.094 to 1.392; this implies that the difference in vessel efficiency is much more important for *Pandalus* than for any other species (Figure 20).

Discussion

Out of the 17 groups considered in this study, only one (group 15) did not show differences in catchability between vessels; for all others the sign of the conversion factor was consistent and clearly indicated that RV Vizconde de Eza had a higher fishing efficiency than the RV Cornide de Saavedra. Even a borderline result, like the case of genus *Sebastes*, suggests higher fishing efficiency in favour of RV Vizconde de Eza. In the case of group 15, the lack of vessel effect is probably more associated to the eclectic composition of this group than to an actual absence of effect.

A simple visual examination of Figures 1-17 also provides support for the analytical results obtained. Most scatter plots present a general distribution pattern with most points above the 1:1 line, as it would be expected from a higher fishing efficiency for RV Vizconde de Eza. In some cases, like *Glyptocephalus cynoglossus* (Figure 2) and operational group 14 (Figure 14), the visual examination of the scatter plots may suggest that the obtained results could be driven by very few fishing sets. A close-up examination of these cases in the region of higher density of data and without the suspected fishing sets (Figures 18 and 19) still shows that in the remaining paired fishing sets, catches from RV Vizconde de Eza are still above the 1:1 line, suggesting that results from randomization tests appear to be fairly robust, even in cases with limited data (e.g. group 14).

When size is introduced as a covariate, only *Pandalus borealis* and *Illex illecebrosus* significantly differed in the size distribution between vessels. A visual examination of the overall size frequency distribution between vessels (Figures 1-17, right panels) also support the analytical results; for most operational groups (the exeptions being *Pandalus borealis* and *Illex illecebrosus*) the size distributions between vessels appeared remarkably similar. Besides *Pandalus borealis* and *Illex illecebrosus*, for which differences are expected, other group that appear to have differences in the overall size frequency distribution is the operational group 16. Despite the differences observed in Figure 16, the high variability in size distributions among individual sets prevents the randomization test from detecting the observed differences as significant. It remains unclear why the size distribution for this particular group is so variable from set to set, but part of the reason could be related with the constituent species of this group; this group includes many small pelagic and bathypelagic species, like Myctophidae, which can form size-segregated schools and exhibit important vertical migration patterns (Willis and Pearcy 1980).

As highlighted by Casas et al. (2004) and González-Troncoso and Casas (2005), although efforts were made to keep fishing procedures in the RV Vizconde de Eza as similar as possible to the ones in place on the RV Cornide de Saavedra, some important differences still existed between the two vessels. The trawl warp diameter, the presence or not of dan leno bobbin, and the greater engine power in the Vizconde de Eza would lead to a wider opening of the gear, and hence, a relatively higher fishing efficiency. Unlike the RV Cornide de Saavedra, the newer vessel is equipped with automatic trawl winch control. This system automatically regulates the tension in the two trawl warps, contributing to preserve the gear geometry during trawling and optimizing the yield of fishing trawls. This new automatic system also reduces gear tugging during trawling operations, improving the stability of the water flow through the fishing gear. A consequence of this smoother gear operation is a reduction in the suction and expulsion of water from the gear caused by tugging, favouring the retention of small organisms (Casas pers. comm.). This difference constitutes a plausible explanation for the size-dependent differences found between vessels for *Pandalus borealis* and *Illex illecebrosus*. Overall, the improvements in fishing operations and performance associated with a better winch control in the RV Vizconde de Eza could account for the detected differences in fishing efficiency.

When the conversion factors for key commercial species obtained in this study are compared with previous analyses (Casas et al 2004 and González-Troncoso and Casas 2005), some important differences emerge. Previous studies used the Robson (1966) approach to estimate conversion factors when considering vessel effects only; while a multiplicative model based on the ratio of the catches by length (Warren 1997) was used when length effects were included. A comparative view of previous conversion factors estimated with the Robson method (using biomass data) and the Relative Catchability Term (b_v) estimated in the present work (using abundance data) is presented in Table 7.

In general terms, and with the only exception of *Macrourus berglax*, all studies found a higher fishing efficiency in favour of RV Vizconde de Eza. However, previous studies found significant size-dependent effects for all key commercial species (Table 7), while this type of effect was only found for *Pandalus borealis* and *Illex illecebrosus* in the present study.

The magnitude of the conversion factors was also different between studies. When size effects are not considered in the model, conversion factors calculated from biomass data can be directly compared with conversion factors based on abundance data. This comparison (Table 7) indicates that conversion factors estimated in this study were consistently higher than the ones calculated previously. When size effects are considered, all studies based the analyses on abundance data. Also in this case, the magnitudes of the conversion factors by size from this study were much higher than estimated in previous studies (Figure 20).

There are several possible and interconnected sources for these differences. This study only considers a subset of the data used in earlier studies. This could increase the uncertainty of the conversion factors estimated here. On the other hand, the approach used here has the advantage of avoiding the additional correction related to the effect of the codend cover in 2003, with its corresponding set of assumptions and errors. For the most part, results from the current analysis indicate that fishes were caught in similar sizes by both vessels. The simple visual comparison of size-distributions between vessels (Figures 1-17, right panels) clearly supports this conclusion, but contradicts the results obtained in previous studies. Although we are convinced that results from this study are robust given the limited data available, the inconsistencies detected between this and earlier works clearly indicate that there is a need for a more in-depth and careful examination of the conversion factors currently available.

In this context, future work should include both a revision of the basic data and the conditions they need to meet to be of valid use for the estimation of conversion factors, as well as the implementation of other modelling approaches, like mixed effect models, which allow considering that the local fish densities encountered by both vessel are the same only on average.

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Table 1.- Summary of number of valid and null paired fishing sets in the comparative fishing exercise carried out during the EU Flemish Cap surveys in 2003 and 2004. Number of paired trawls for which difference in distance between vessels is greater tan 20% is also shown.

	2003			2004		
	valid	null	total	valid	null	total
Number of sets for the RV *Vizconde de Eza*	3	51	54	61	8	69
Number of sets for the RV *Cornide de Saavedra*	54	0	54	67	2	69
Number of sets with differences in towed distance >20% between vessels			1			4
Final number of valid paired fishing sets			2			57

Table 2. Species composition of operational groups 14 to 17; groups 1 to 13 were conformed by single species or genus (Table 3). Body shape and typical habitat were used as grouping criteria.

Operational Group	Order	Species
Group 14	Anguilliformes	*Nemichthys scolopaceus* *Serrivomer beani* *Synaphobranchus kaupi*
	Aulopiformes	*Arctozeus risso* *Magnisudis atlantica*
	Notacanthiformes	*Notacanthus chemnitzii*
Group 15	Gadiformes	*Antimora rostrata* *Barbada argentatus* *Coryphaenoides rupestris* *Enchelyopus cimbrius* *Graidopsarus ensis* *Melanogrammus aeglefinus* *Micromesistius poutassou* *Pollachius virens* *Urophycis tenuis*
	Perciformes	*Chiasmodon niger* *Howella sherborni* *Lepbolinus maculatus* *Lycenchelys paxillus* *Lycodonus flagellicauda*
	Scorpaeniforme	*Ulcina olriki*
	Squaliformes	*Centroscyllium fabricii*
Group 16	Myctophiformes	*Benthosema glaciale* *Ceratoscopelus maderensis* *Lampadena speculigera* *Lampanycthus sp.* *Myctophidae* *Myctophidae sp.* *Myctophum punctatum* *Notoscopelus*
	Osmeriformes	*Alepocephalidae* *Argentina silus* *Bathylagus euryops* *Mallotus villosus* *Normichthys operosus* *Xenodermichthys copei*
	Stephanoberyciformes	*Poromitra megalops* *Scopelogadus beani*
	Stomiiformes	*Argyropelecus hemigymnus* *Argyropelecus sp.* *Chauliodus sloani* *Flagellostomias boureeri* *Gonostoma elongatum* *Malacosteus niger* *Maurolicus muelleri* *Stomias boa*
Group 17	Lophiiformes	*Lophius americanus*
	Pleuronectiformes	*Hippoglossus hippoglossus*
	Rajiformes	*Amblyraja radiata* *Bathyraja spinicauda* *Dipturus linteus* *Malacoraja senta* *Rajella fyllae*

Table 3. Number of fishing sets by vessel and total number of relevant paired fishing sets for each operational group.

Operational group	Group number	RV Cornide de Saavedra	RV Vizconde de Eza	Relevant Paired fishing sets
Gadus morhua	1	21	23	27
Glyptocephalus cynoglossus	2	29	36	42
Hippoglossoides platessoides	3	36	38	41
Illex illecebrosus	4	42	52	54
Lumpenus lumpretaeformis	5	26	41	43
Macrourus berglax	6	11	12	13
Nezumia bairdi	7	33	35	38
Pandalus borealis	8	38	49	50
Reinhardtius hippoglossoides	9	48	47	50
Urophycis chesteri	10	36	38	39
Genus *Anarhichas*	11	55	57	58
Genus *Lycodes*	12	38	42	42
Genus *Sebastes*	13	56	58	58
Group 14	14	7	11	12
Group 15	15	30	36	45
Group 16	16	23	39	43
Group 17	17	52	56	57

Table 4. Results for Model 1: Vessel effect only.

Operational group	Relevant Paired fishing sets	Outliers	Valid sets for analysis	p-value from randomization test	β_v	b_v
Gadus morhua	27	5	22	0.043	0.465	1.593
Glyptocephalus cynoglossus	42	1	41	0.000	0.453	1.574
Hippoglossoides platessoides	41	1	40	0.000	0.643	1.902
Illex illecebrosus	54	2	52	0.000	0.492	1.636
Lumpenus lumpretaeformis	43	3	40	0.000	0.619	1.856
Macrourus berglax	13	0	13	0.021	0.486	1.626
Nezumia bairdi	38	0	38	0.012	0.278	1.321
Pandalus borealis	50	1	49	0.000	2.032	7.631
Reinhardtius hippoglossoides	50	0	50	0.000	0.33	1.391
Urophycis chesteri	39	1	38	0.000	0.764	2.147
Genus *Anarhichas*	58	0	58	0.000	0.625	1.868
Genus *Lycodes*	42	1	41	0.000	0.551	1.735
Genus *Sebastes*	58	1	57	0.063	0.205	1.227
Group 14	12	0	12	0.007	0.251	1.285
Group 15	45	1	44	0.390	-0.067	0.935
Group 16	43	0	43	0.015	0.588	1.801
Group 17	57	1	56	0.042	0.224	1.252

Table 5. Results for Model 2: Vessel and fish size effects.

Operational group	Relevant Paired fishing	Outliers	Valid Trawls	p-value from randomization test	β'_v	β_l
Gadus morhua	27	1	26	0.557	1.920	-0.018
Glyptocephalus cynoglossus	42	2	40	0.763	1.526	-0.018
Hippoglossoides platessoides	41	3	38	0.960	1.285	-0.012
Illex illecebrosus	54	0	54	0.035	3.792	-0.189
Lumpenus lumpretaeformis	43	3	40	0.808	0.493	0.006
Macrourus berglax	13	0	13	0.465	0.380	0.008
Nezumia bairdi	38	0	38	0.368	0.781	-0.073
Pandalus borealis	50	3	47	0.000	7.506	-0.287
Reinhardtius hippoglossoides	50	4	46	0.900	0.442	-0.006
Urophycis chesteri	39	2	37	0.257	1.293	-0.029
Genus *Anarhichas*	58	1	57	0.103	0.925	-0.009
Genus *Lycodes*	42	5	37	0.078	1.783	-0.046
Genus *Sebastes*	58	3	55	0.547	0.421	-0.016
Group 14	12	0	12	0.688	-0.107	0.01
Group 15	45	2	43	0.118	-0.369	0.012
Group 16	43	1	42	0.220	2.615	-0.084
Group 17	57	0	57	0.762	0.031	0.002

Table 6. Model parameters and Relative Catchability Terms (b_v) for those operational groups with significant differences in catchability between the two vessels, or with borderline significance.

Operational groups	β_v or β'_v	β_l	b_v	% Difference
Gadus morhua	0.465		1.593	59.3
Glyptocephalus cynoglossus	0.453		1.574	57.4
Hippoglossoides platessoides	0.643		1.902	90.2
Lumpenus lumpretaeformis	0.619		1.856	85.6
Macrourus berglax	0.486		1.626	62.6
Nezumia bairdi	0.278		1.321	32.1
Reinhardtius hippoglossoides	0.33		1.391	39.1
Urophycis chesteri	0.764		2.147	114.7
Genus *Anarhichas*	0.625		1.868	86.8
Genus *Lycodes*	0.551		1.735	73.5
Genus *Sebastes*	0.205		1.227	22.7
Group 14	0.251		1.285	28.5
Group 16	0.588		1.801	80.1
Group 17	0.224		1.252	25.2
Illex illecebrosus	3.792	-0.189	exp(B'v+B1*FL)	
Pandalus borealis	7.506	-0.287	exp(B'v+B1*FL)	

Table 7. Conversion factors obtained with the Robson method by González-Troncoso and Casas (2005) and the Relative Catchability Term (b_v) estimated in this study for key main commercial species.

	González-Troncoso and Casas (2005)		This Study	
	Vessel Effect	**Effect by size**	**Vessel Effect**	**Effect by size**
Gadus morhua	1.0998	Yes	1.593	No
Hippoglossoides platessoides	1.3336	Yes	1.902	No
Gen Sebastes	1.1213	Yes	1.227	No
Reinhardtius hippoglossoides	1.0159	Yes	1.391	No
Macrourus berglax	0.8405	Yes	1.626	No

Figure 1. *Gadus morhua*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

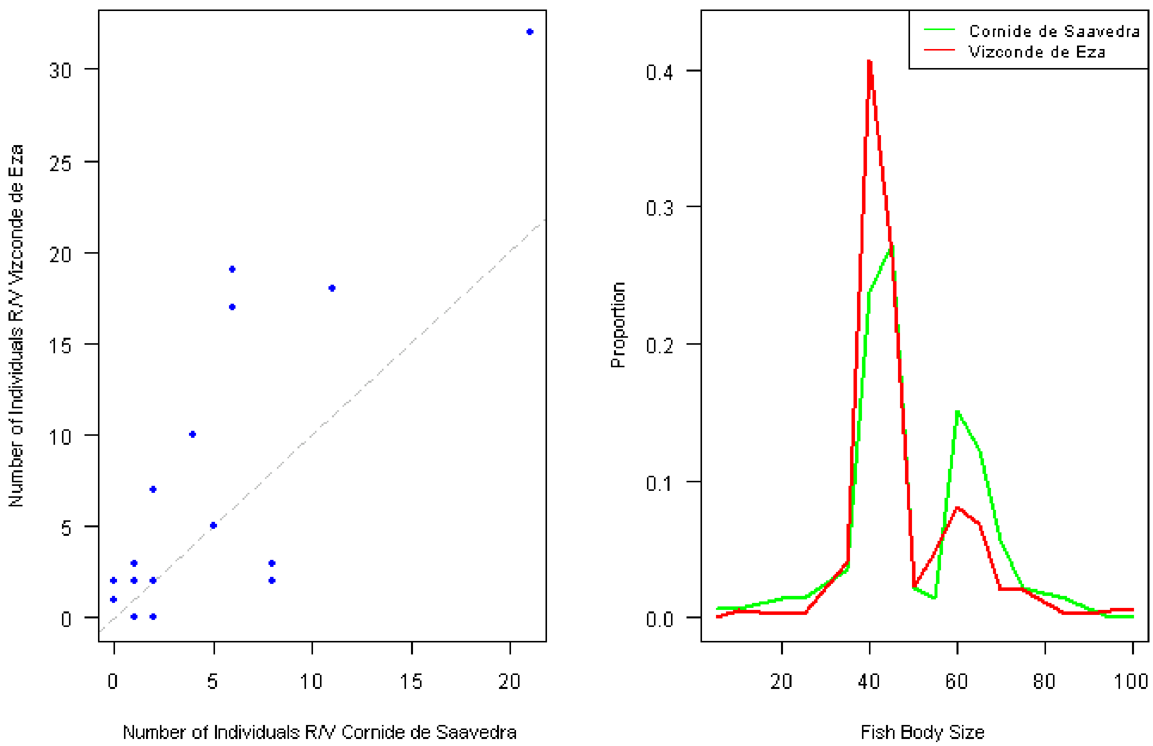


Figure 2.- *Glyptocephalus cynoglossus.* The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

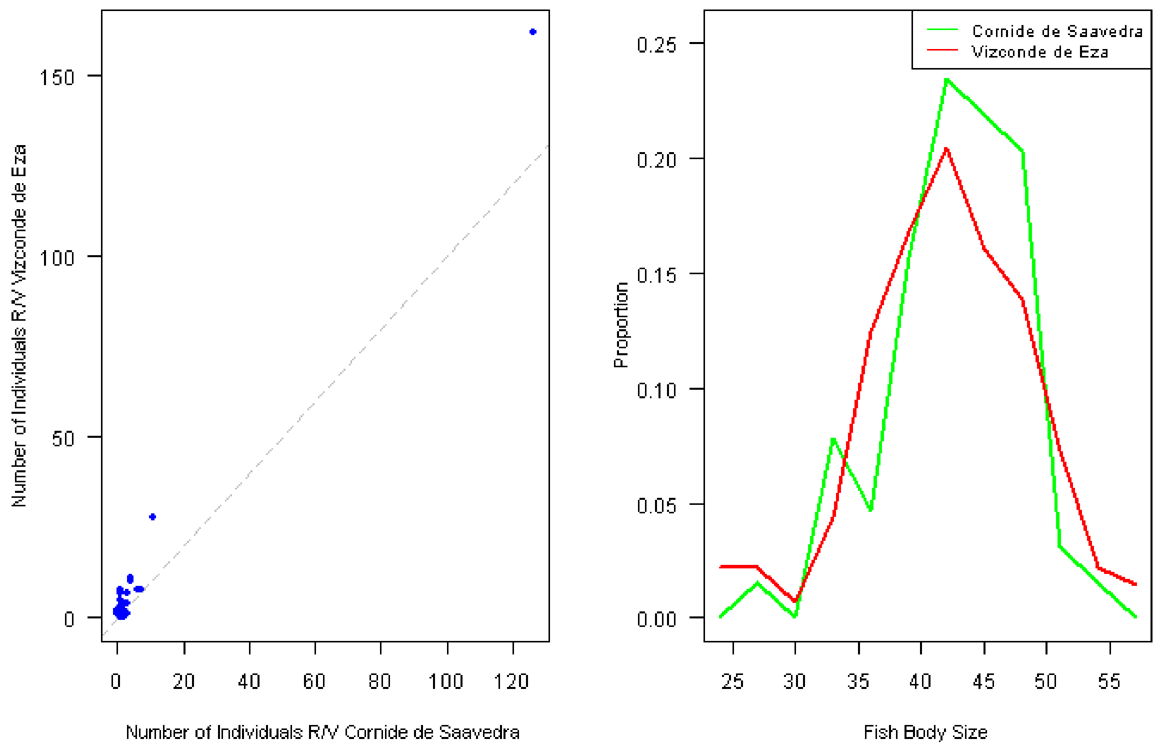


Figure 3. *Hipoglossoides platessoides*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

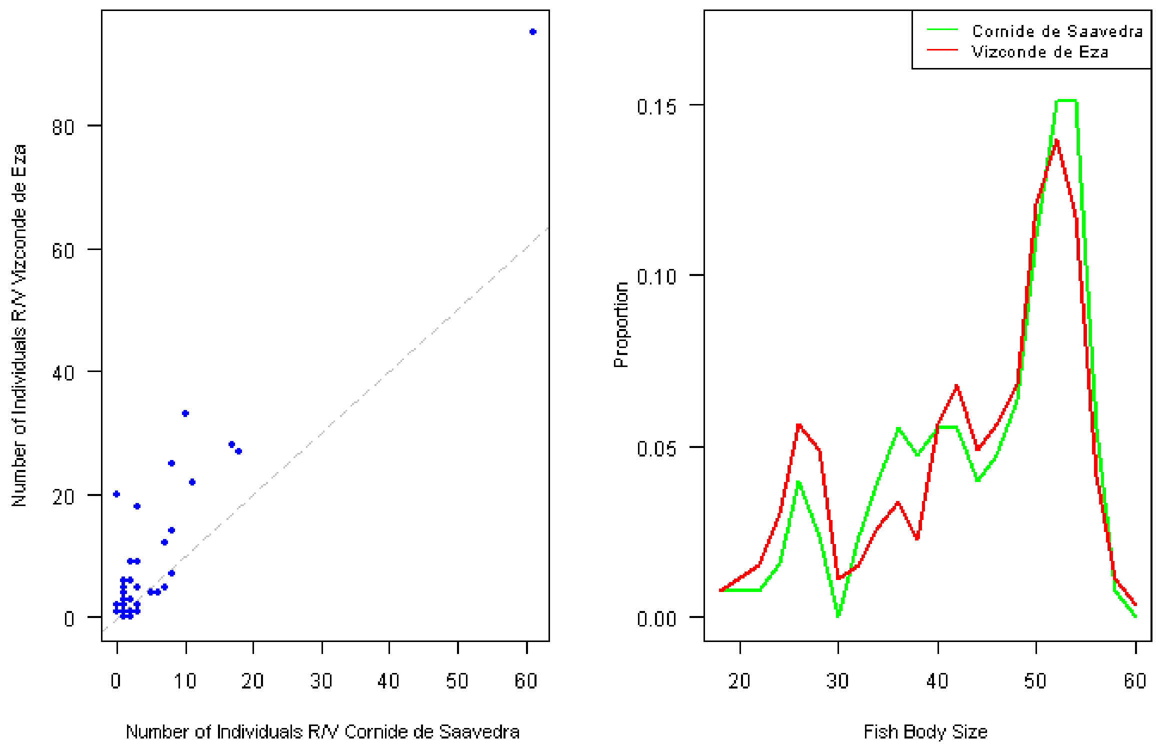


Figure 4. *Ilex illecebrosus*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

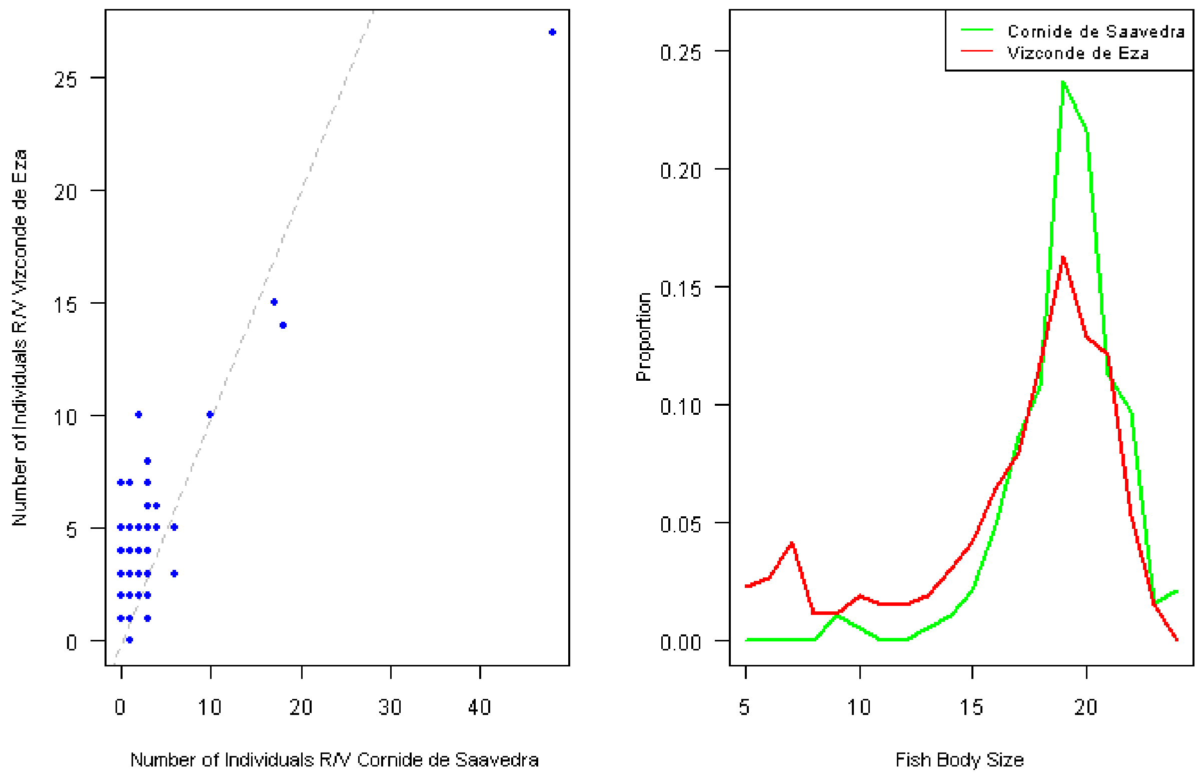
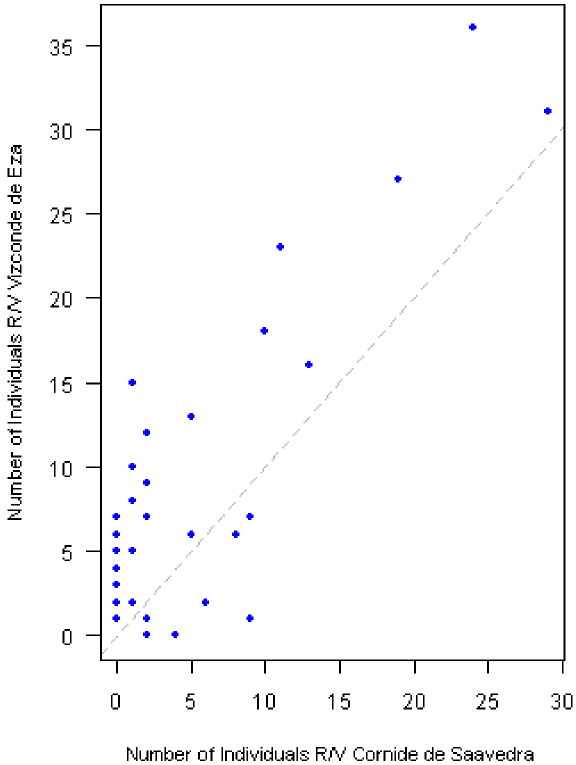


Figure 5. *Lumpenus lampretaeformis*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.



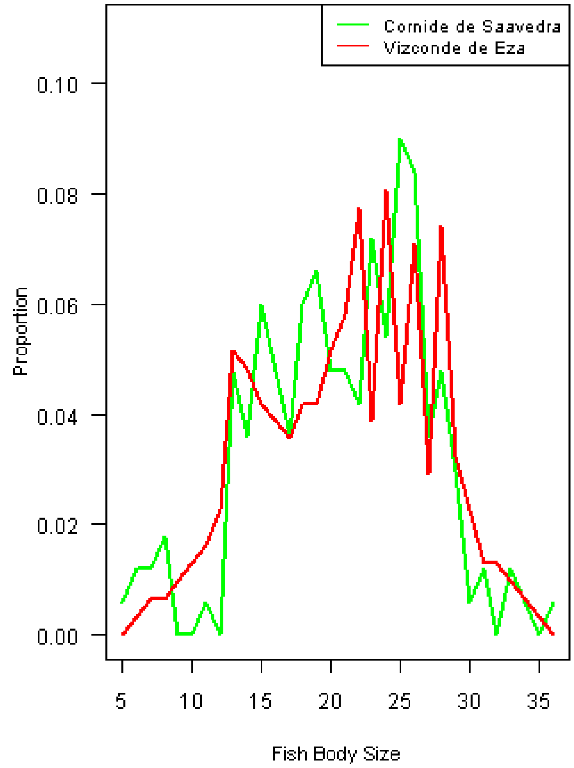


Figure 6. *Macrourus berglax*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

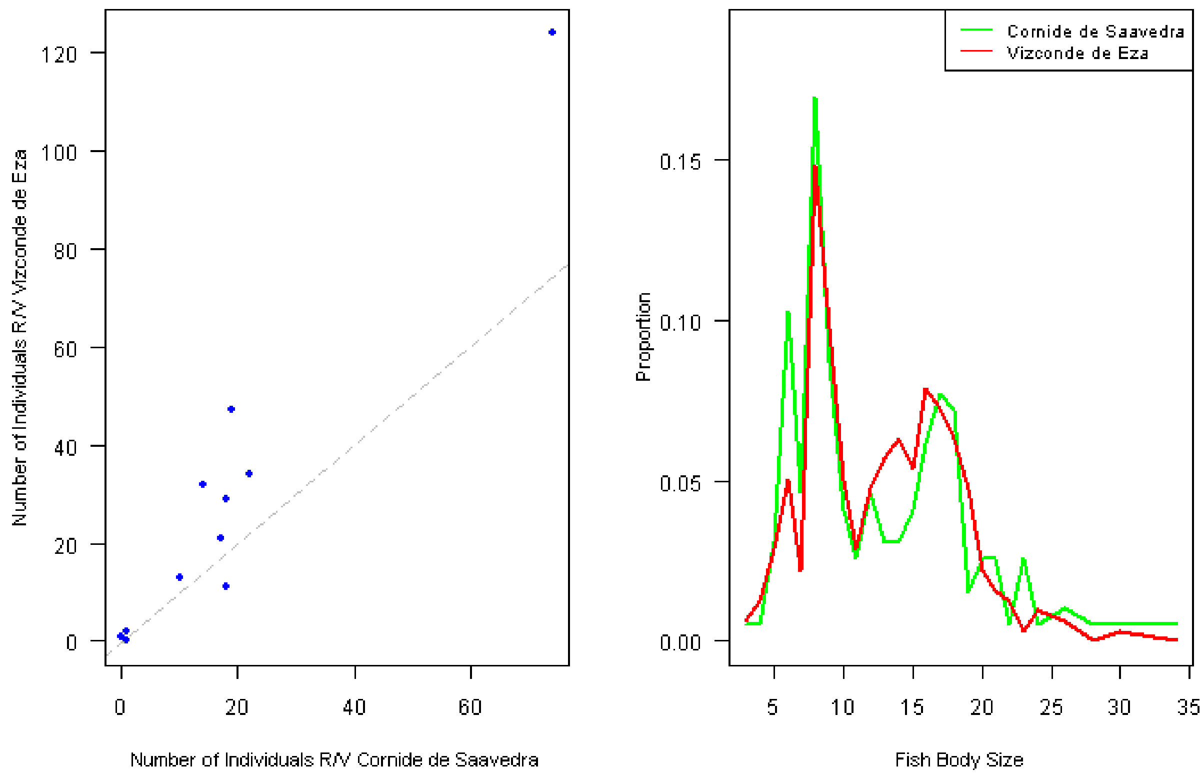
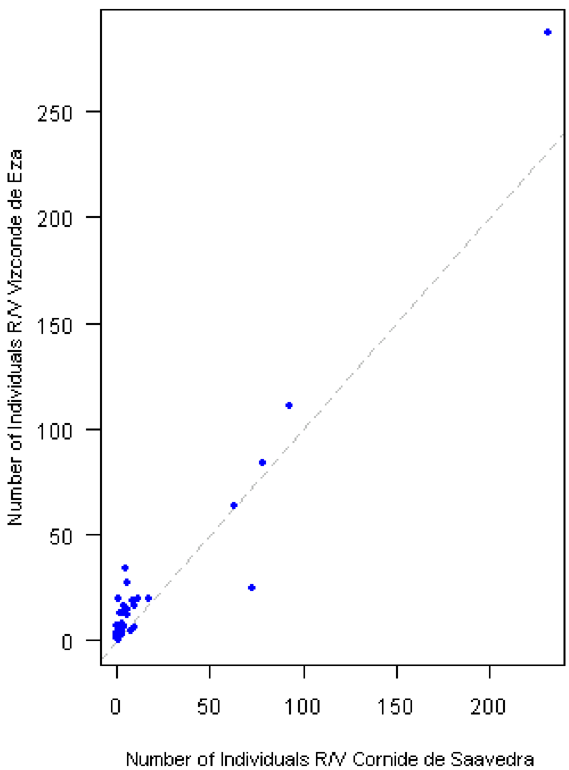


Figure 7. *Nezumia bairdii*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.



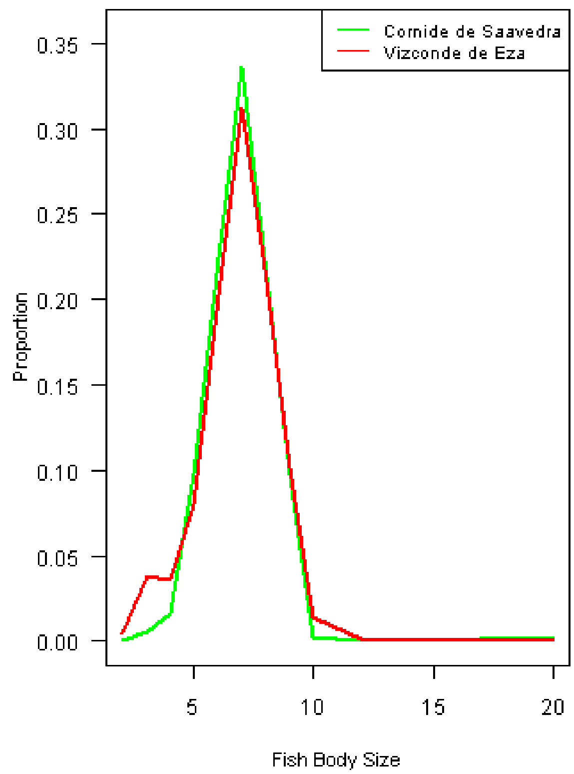


Figure 8. *Pandalus borealis*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

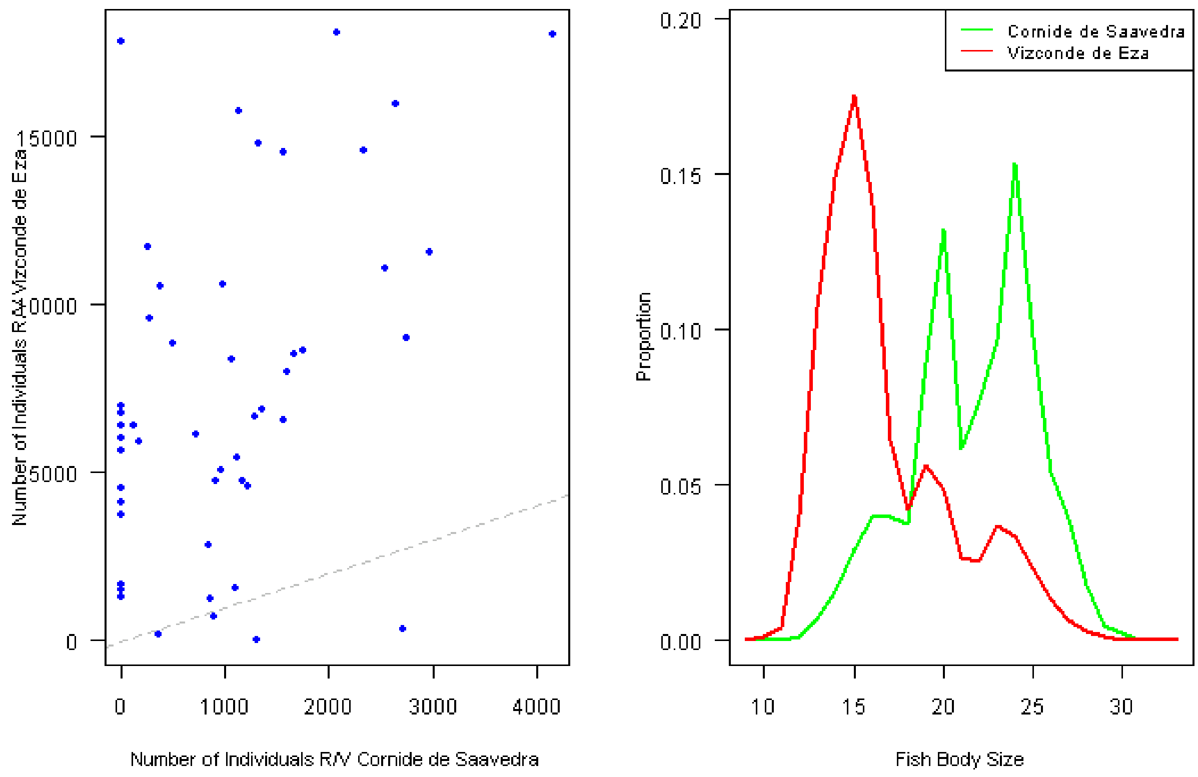


Figure 9. *Reinhardtius hippoglossoides*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

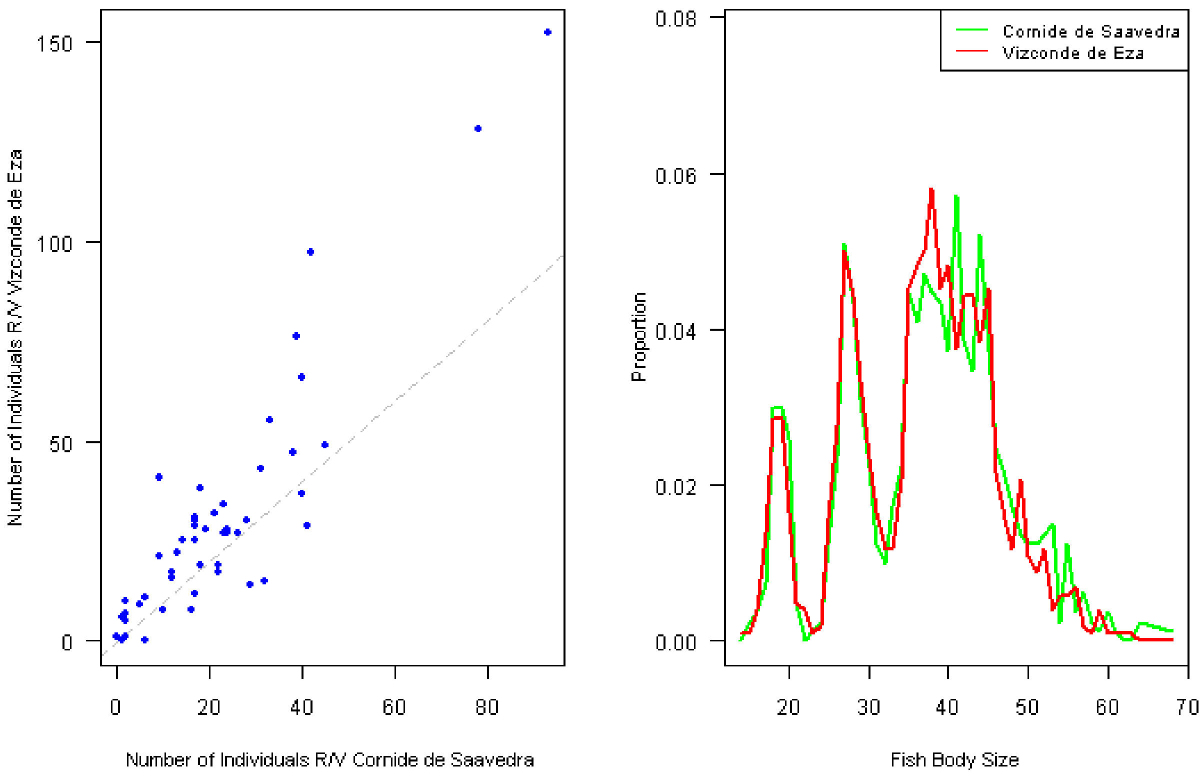


Figure 10. *Urophycis chesteri*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

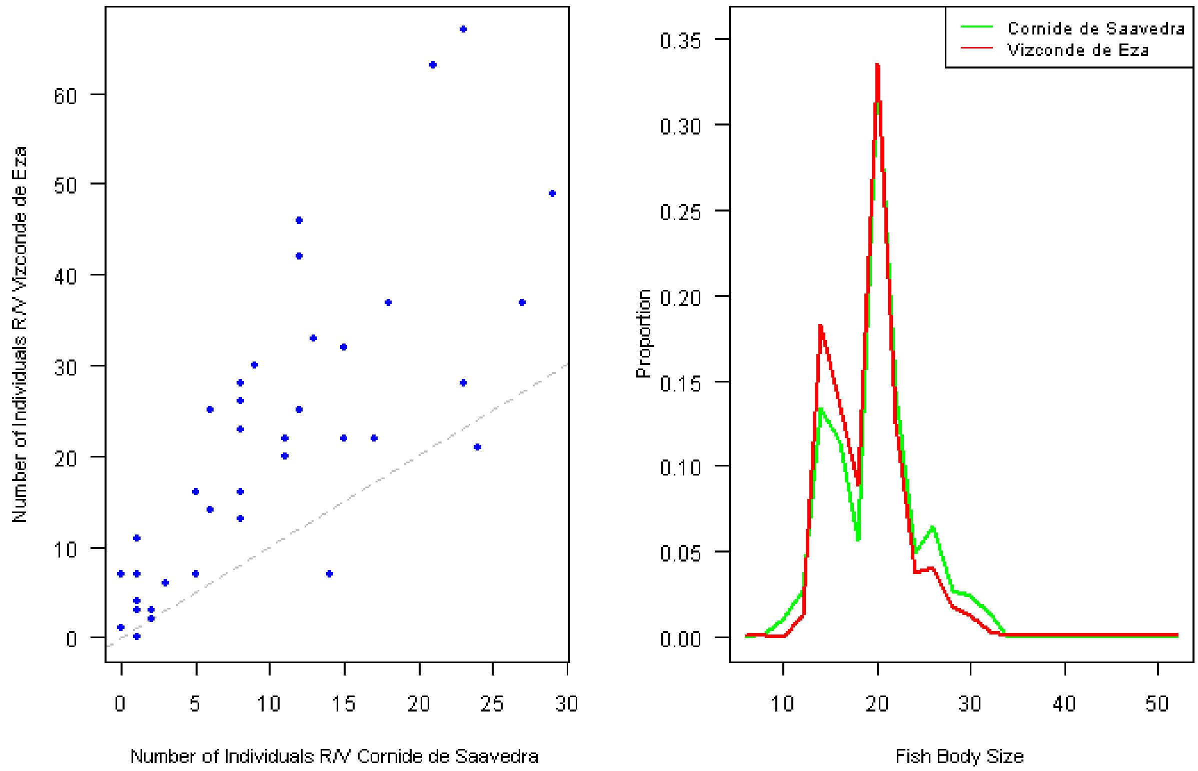


Figure 11. Genus *Anarhichas*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

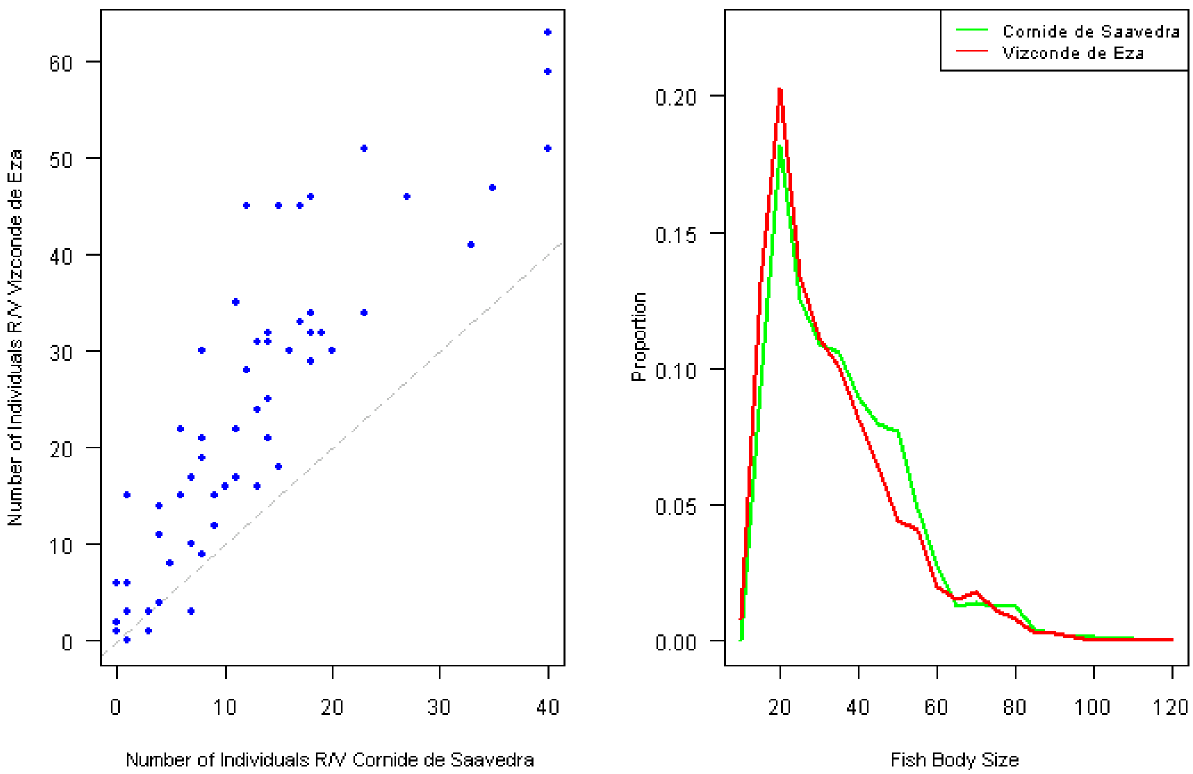


Figure 12. Genus *Lycodes*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

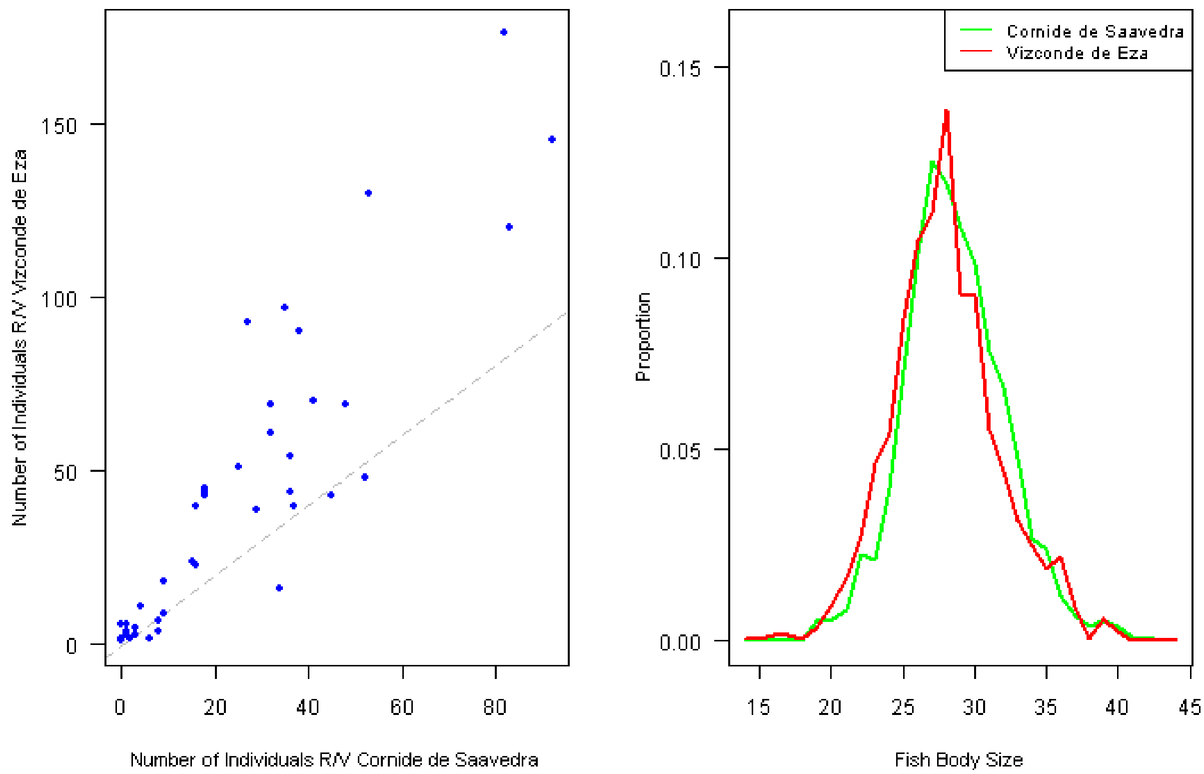


Figure 13. Genus *Sebastes*. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

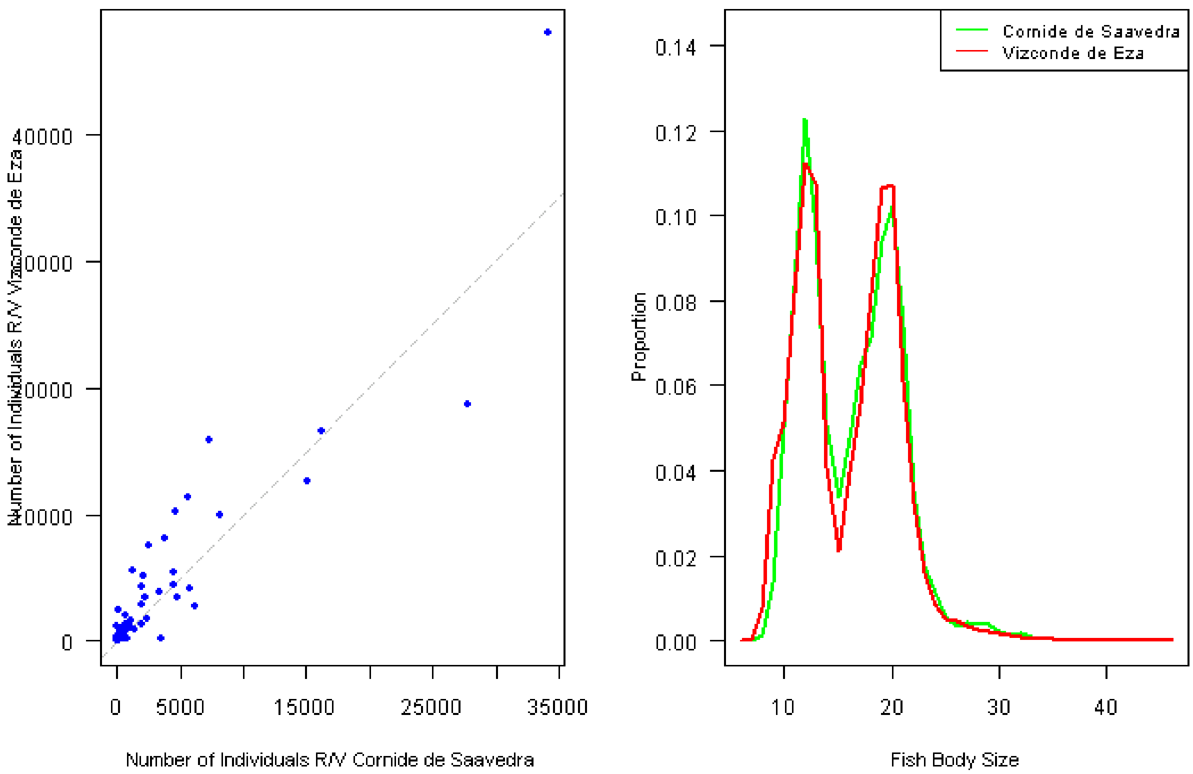


Figure 14. Operational Group 14: Anguliformes, Notacanthiformes, Aulopiformes. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

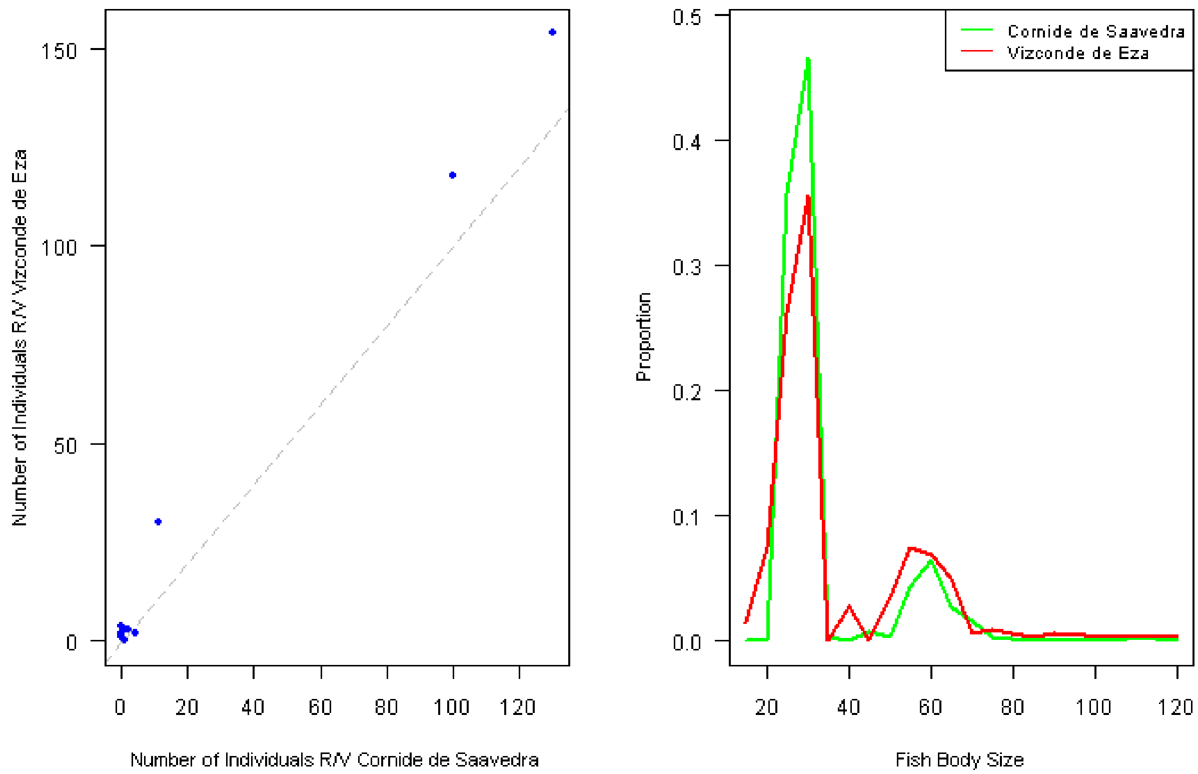
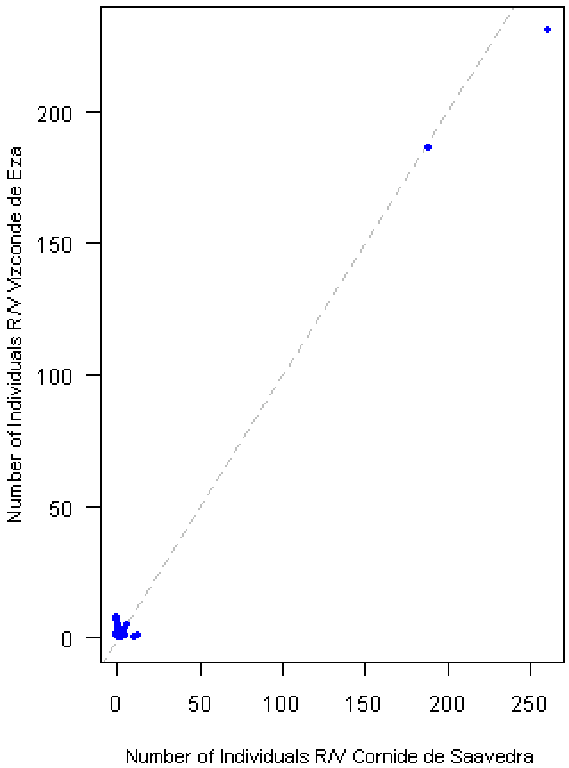


Figure 15. Operational Group 15: Gadiformes, Scorpaeniformes, Rajiformes, Squaliformes. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.



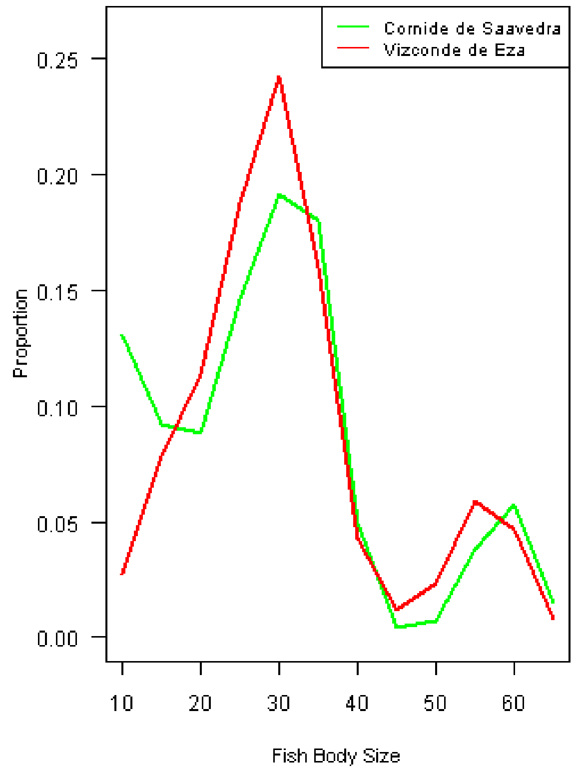


Figure 16. Operational Group 16: Myctophyformes, Osmeriformes, Stephanobericiformes, Stomiiformes. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

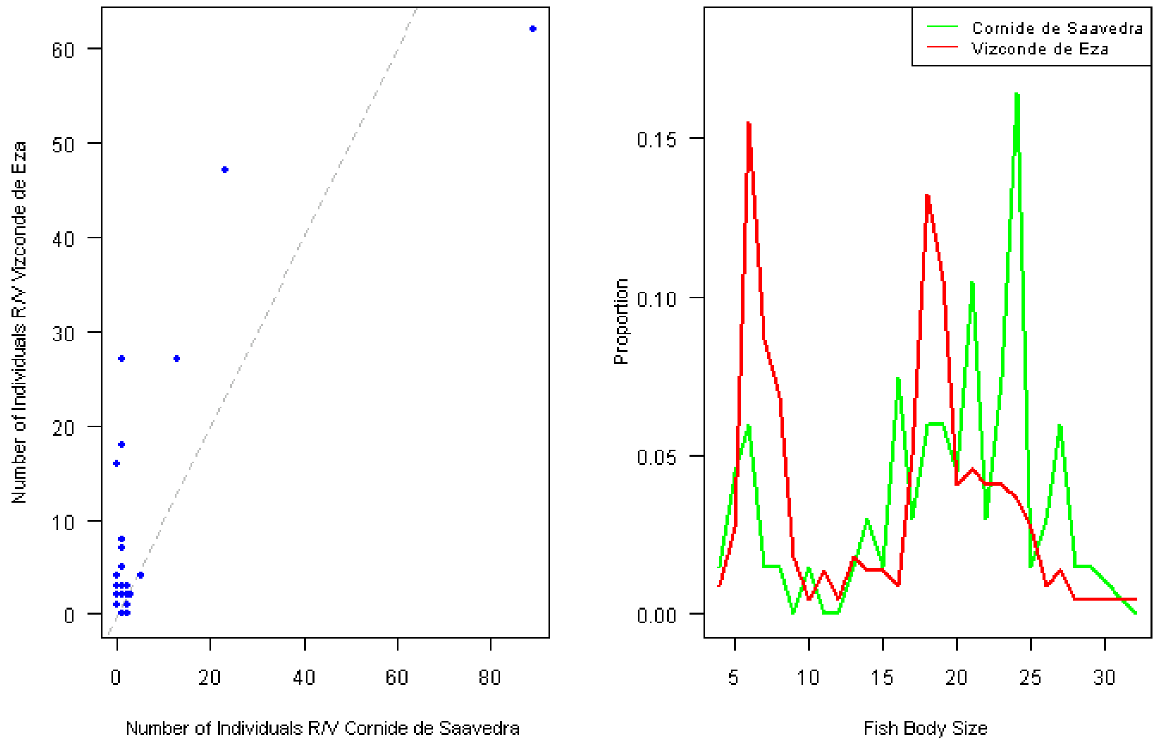


Figure 17. Operational Group 17: Rajiformes, Lophiiformes, Pleuronectiformes. The graph on the left shows the number of individuals caught in each relevant paired set for this group; the 1:1 line (grey dotted line) is provided for visual reference. The graph on the right shows the relative size distribution in each vessel over all relevant sets.

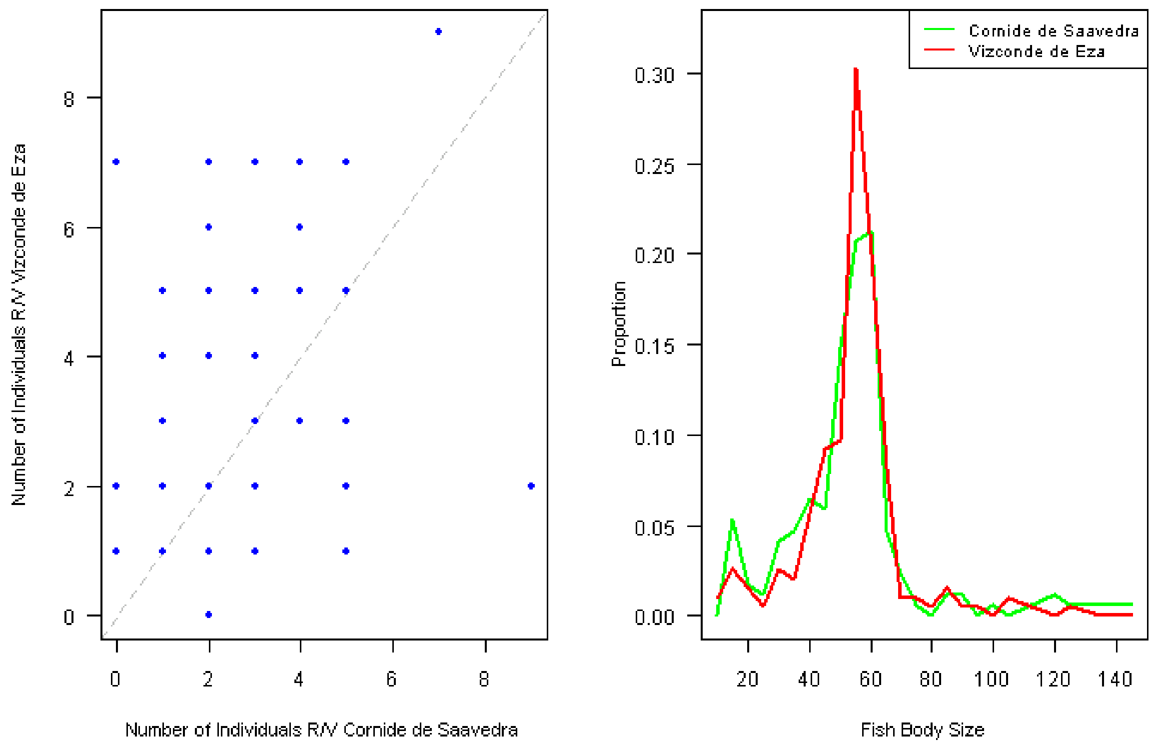


Figure 18. Scatter plot of the Operational Group 14 without the two paired fishing trawls with highest catches.

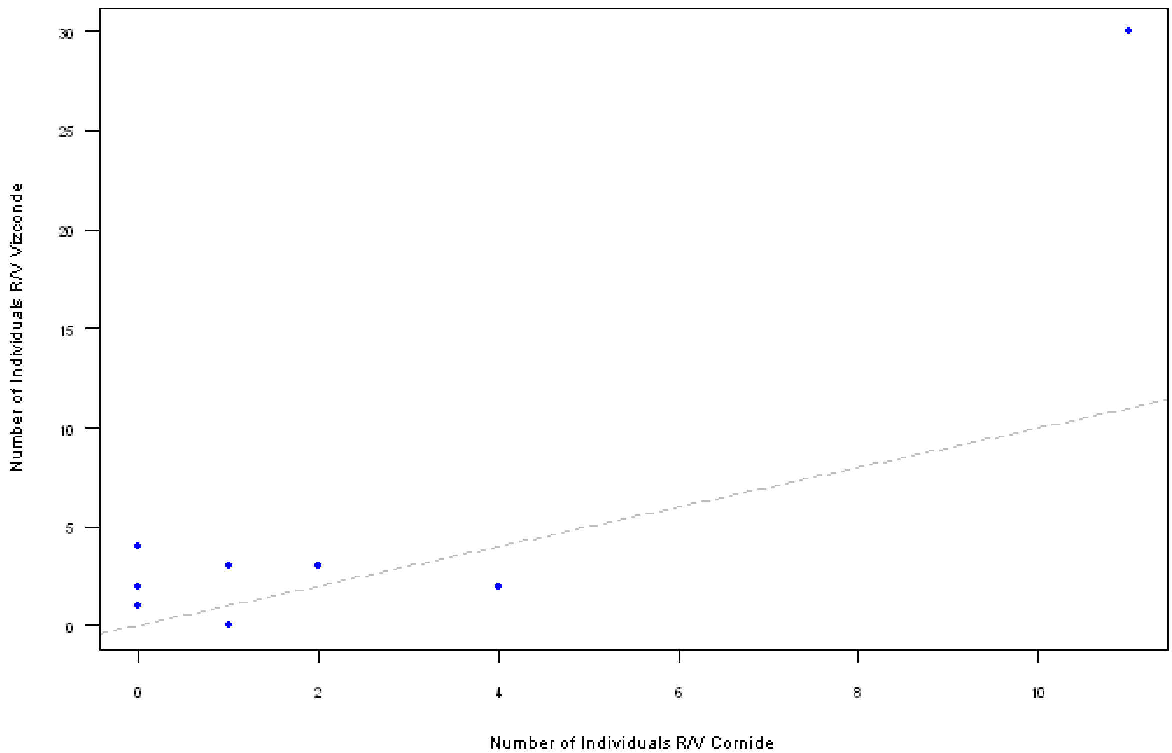


Figure 19. *Glyptocephalus cynoglossus*. In this scatter plot the paired set with highest catches in both vessels has been excluded.

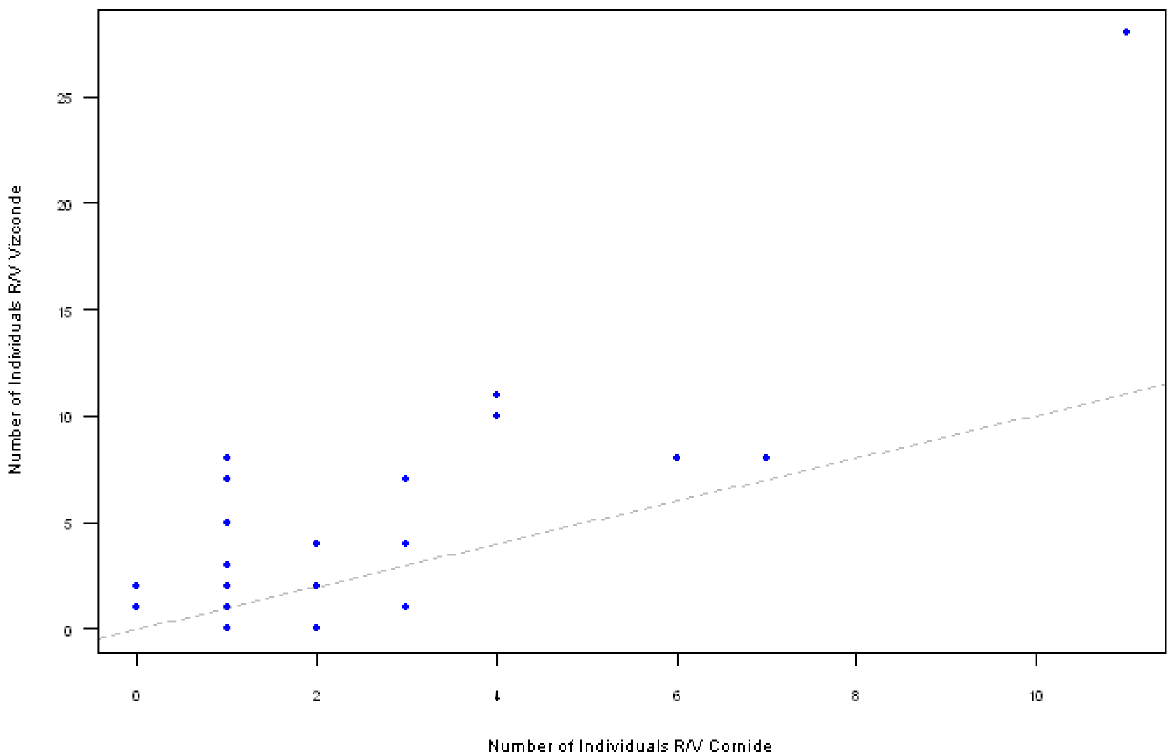


Figure 20. Comparison of *Pandalus borealis* conversion factors by length resulting from Casas et al (2004) and the present study.