Falkland Islands Fisheries Department

Skate (Rajiformes) Stock Assessment, 2015

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June 2016

Index

Summary

1. In 2015, skate catch by skate-licensed trawlers was reported at 2365.3 tonnes, out of a total skate catch (all fisheries) of 6487.2 tonnes. The total skate catch in 2015 was the third-highest since 1993, after 2011 and 2012
2. Stock assessment of the multi-species skate assemblage was calculated with a Schaefer production model. The model was optimized on CPUE indices of Korean and Spanish target trawl catches north of 51°S, with penalty functions for survey biomass estimates calculated in 2010 and 2013, carrying capacity ≥ initial biomass, and current biomass > maximum sustainable yield.
3. The Schaefer production model estimated skate biomass north of 51°S in 2015 at 39,733 tonnes (95% confidence interval 33,838 to 81,133 tonnes) and maximum sustainable yield at 6,726 tonnes (95% confidence interval 5,907 to 60,079 tonnes).
4. Among the four predominant species, individual species CPUE time series continued to show increasing trends for *Bathyraja albomaculata* and *Bathyraja brachyurops*. The CPUE time series for *Zearaja chilensis* showed a significant downturn for the past two years, and the CPUE trend for *Bathyraja griseocauda* levelled off with a non-significant decreasing trend.

Introduction

Skate catches (Rajiformes) have been reported in Falkland Islands waters since 1987. Skate catches were low until the stocks were commercially recognized by a Korean trawl fleet in the early 1990s (Wakeford et al. 2005), but rapidly increased >5000 tonnes year^{-1}. Given the strong targeted effort, skate trawling was licensed separately from other trawl fisheries starting in 1994 (Wakeford et al. 2005). Two skate fishing regions were identified: north and south of the Falkland Islands, and the southern region soon showed signs of decreasing catch (Agnew et al. 2000; Wakeford et al. 2005). As a conservation measure, directed fishing for skates was prohibited south of 51°S in 1996 (Agnew et al. 1999).

Directed fishing for skates in the north has continued annually. In 2015, skate catch by skate-licensed trawlers was 2365.3 tonnes (Table 1), taken in 54 grid units north of 51 ºS (Figure 1). Of these 54 grid units, 66.9% of skate catch and 48.6% of skate-license effort occurred in just 8 grid units that mainly followed the 200 m isobath (Figure 1). Skate bycatch by other commercial bottom trawls (licensed for finfish or Falkland calamari) was 3954.5 tonnes, taken in 142 grid units around the Falkland Islands. Of these 142 grid units, 47 were among the 54 grid units that had also been fished with skate license; and these accounted for 73.9% of the skate catch by other commercial bottom trawls. Of the total skate bycatch by other commercial bottom trawls, 21.7% was taken by vessels that had also held skate licenses during the year, while representing 14.9% of the effort. Additionally 27.6 tonnes of skate in 2015 were taken as bycatch under longline (L) license, and 0.3 tonnes under *Illex* (B) license. No skate bycatch was taken under surimi (S) license. Total experimental (E license) catch of skate in 2015 was 10.4 tonnes.

FIFD observers sampled skates on 19 fishing vessels in 2015, over a total of 145 sample stations. Fifteen skate species were identified, representing most of the known species in Falkland Islands waters (Arkhipkin et al. 2012). By specimen numbers, 34.7% of skate samples were *Bathyraja brachyurops*, 27.9% *Bathyraja albomaculata*, 18.4% *Zearaja chilensis*, 5.3% *Bathyraja griseocauda*, 4.4% *Bathyraja macloviana*, 3.3% *Amblyraja doellojuradoi*, 2.4% *Bathyraja scaphiops*, 1.3% *Psammobatis* spp., 0.9% *Bathyraja multispinis*, 0.5% *Bathyraja cousseauae*, 0.3% *Dipturus argentinensus*, 0.3% *Amblyraja cf.*

georgiana, 0.1% *Bathyraja papilionifera*, 0.1% *Bathyraja magellanica*, 0.1% *Bathyraja meridionalis*.

Stock assessment for license allocation was again based on the multi-species skate complex, as species are not identified in vessel catch reports (Agnew et al. 2000, Wakeford et al. 2005, Winter et al. 2015). However, annual CPUE trends are reported for six major species of interest (Winter et al. 2015).

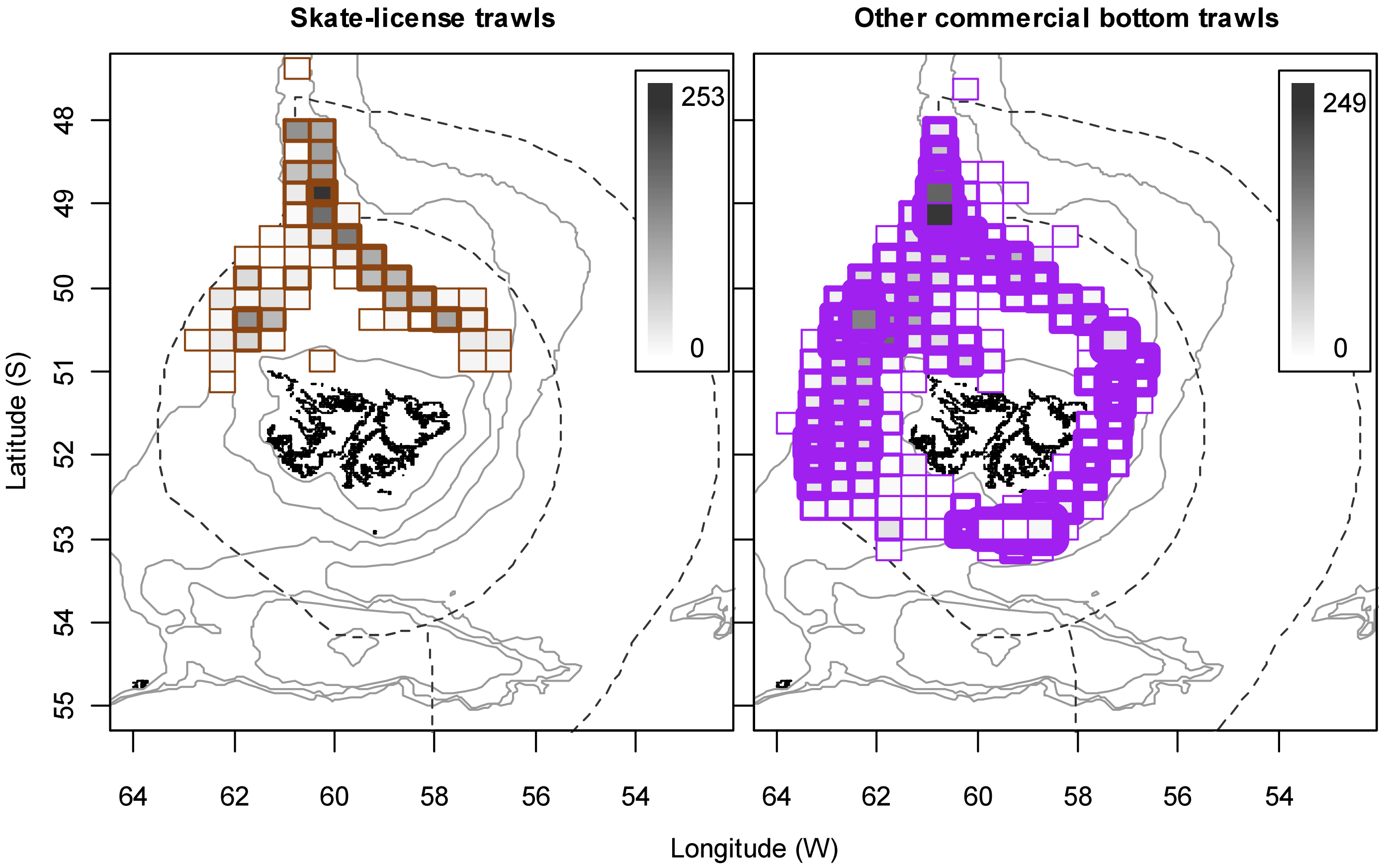

Figure 1. Distribution of skate catches by grid under skate license (left) and other bottom-trawl licenses (right) in 2015. Thickness of grid lines is proportional to the number of vessel-days (1 to 17 for skate license, left; 1 to 256 for other bottom-trawl licenses, right). Gray-scale is proportional to the skate catch biomass (maximum 253.3 tonnes in one grid unit for skate license, left; maximum of 248.8 tonnes for other bottom-trawl licenses, right).

Methods

The skate stock assessment calculated last year (Section 5 in FIFD, 2015) was updated with the most recent year's catch and effort report data. All skate catches from all years are entered according to the revised conversion factors (Winter and Pompert 2014). The current skate stock assessment was calculated as a Schaefer production model (Schaefer 1954), expressed as a difference equation:

$$B_{t+1} = B_t + rB_t\left(1-\frac{B_t}{K}\right) - C_t$$

where B_t and C_t are the stock biomass and catch in year t; r is the intrinsic population growth rate and K is the carrying capacity. The Schaefer production model was optimized on time series indices of standardized CPUE. In previous years (e.g., FIFD 2015) the CPUE index of Korean skate-license trawls north of 51°S was used solely for optimization, as this CPUE index had been found to be the most consistent (Laptikhovsky et al. 2011). However, recent revelations of potential catch misreporting in the skate fishery (B. Meehan, FIFD, pers. comm.) have motivated an approach to mitigate reliance on one single index. For this assessment the Schaefer production model was instead optimized on an objective function comprising the negative log-likelihood functions of both Korean and Spanish skate-license CPUE trawl indices north of 51°S:

$$\mathrm{L}\{\mathrm{CPUE}_{Korea\ N}, \mathrm{CPUE}_{Spain\ N} \mid \text{parameters}\} = \mathrm{L}\{\mathrm{CPUE}_{Korea\ N} \mid \mathrm{K}, \mathrm{B}_1, \mathrm{r}, \mathrm{q}_{Korea\ N}\} + \mathrm{L}\{\mathrm{CPUE}_{Spain\ N} \mid \mathrm{K}, \mathrm{B}_1, \mathrm{r}, \mathrm{q}_{Spain\ N}\}$$

where

$$\mathrm{L}\{\mathrm{CPUE}_{Korea\ N} \mid \mathrm{K}, \mathrm{B}_1, \mathrm{r}, \mathrm{q}_{Korea\ N}\} = \mathrm{n}\left(\log(\sigma_{Korea\ N}) + \frac{\log(2\pi)}{2}\right) + \frac{\sum_t\left(\log(\mathrm{B}_t) - \log(\mathrm{CPUE}_{Korea\ N\,t} / \mathrm{q}_{Korea\ N})\right)^2}{2\sigma^2_{Korea\ N}}$$

Equivalently, substitute *Spain N* for *Korea N*; notation following Hilborn and Mangel (1997); n is the length of time series t observations, q is the catchability coefficient of the CPUE index expressed as kg of skate catch per trawl hour, and σ is the standard deviation between $\log(B_t)$ and $\log(CPUE_t / q_t)$:

$$\sigma_{Korea\ N} = \sqrt{\overline{\left(\log(\mathrm{B}_t) - \log(\mathrm{CPUE}_{Korea\ N\,t} / \mathrm{q}_{Korea\ N})\right)^2}}$$

CPUE $_{Korea\ N}$ and CPUE $_{Spain\ N}$ were standardized for latitude, longitude, month and depth using generalized additive models (GAM). Annual skate catch and effort data from 1989 through 2015 were included. Skate licenses have been implemented since 1994 (Wakeford et al. 2005), and a probabilistic algorithm (FIFD 2013) was used to infer which Korean trawls were actually targeting skates in the years 1989 to 1993, before the issuance of skate licenses. The two earliest years 1987 and 1988 were not included because catch reporting did not yet distinguish trawls from jigging or longline. The same probabilistic assignment of 1989 to 1993 Korean skate target trawls as last year (FIFD 2015) was applied to the current assessment. The algorithm was not calculated to infer Spanish trawls targeting skates in 1989 to 1993, because in the following years 1994 to 1996, which are used as the template, only 12 days of skate license trawling were taken by a single Spanish vessel (during 1995).

Biomass in the first year of the fishery ($B_1 = B_{1989}$) was optimized as a free parameter in the Schaefer production model. B_1 is sometimes assumed to equal the carrying capacity K (Punt 1990, Hilborn and Mangel 1997), but as skate fishing in Falkland Islands waters was ongoing before 1989 the assumption is unreliable for this fishery, and K and B_1 were optimized separately along with r, $q_{Korea\ N}$, and $q_{Spain\ N}$.

Four penalty terms were added to the Schaefer production model to stabilize the optimization. The first two penalty terms related to skate biomass estimates from FIFD skate surveys conducted in 2010 (Arkhipkin et al. 2010) and 2013 (Pompert et al. 2014). In either survey the 26 grid units were occupied that represented the historic concentration of the skate target fishery (Payá et al. 2008). Because the actual commercial fishery can shift around in any year, the inference was made that the proportion of total commercial skate catch taken in the top 26 grids (not necessarily the exact same ones) should reflect the ratio of survey area biomass to total biomass north of 51 °S (Laptikhovsky et al. 2011). Survey area biomasses in 2010 and 2013 were estimated from swept-area samples with variability distributions calculated by bootstrap re-sampling (Arkhipkin et al. 2010, Pompert et al. 2014). The proportions of total commercial skate catch taken in the top 26 grids in 2010 and 2013 likewise had variability distributions calculated by bootstrap re-sampling. Combining the two variability distributions, composite estimates of total skate biomass had 95% confidence limits of:

2010	17,832.7 to 50,198.3 tonnes
2013	14,494.1 to 82,840.4 tonnes

The penalty function was implemented as the log squared difference:

$$\mathrm{P}\{\mathrm{B}_{survey\ 2010}, \mathrm{B}_{2010} \mid \mathrm{K}, \mathrm{B}_1, \mathrm{r}, \mathrm{q}_{Korea\ N}\} = \emptyset \frac{\left(\log\left(\mathrm{B}_{survey\ 2010\ min\ /\ max\ 95\%}\right) - \log(\mathrm{B}_{2010})\right)^2}{2\sigma^2_{Korea\ N}}$$

where $\emptyset = 0$ if the B_{2010} iteration of the optimization was within the 95% confidence limits of the 2010 survey estimate, and $\emptyset = 1$ if the B_{2010} iteration was outside the 95% confidence limits of the 2010 survey estimate. (Again, equivalently substitute *Spain N* for *Korea N*, and / or survey 2013 for survey 2010). The third penalty term was for $K \geq B_1$ (Prager 1994), and the fourth penalty term was for $B_{2015} \geq$ maximum sustainable yield (MSY). The third and fourth penalty terms were likewise calculated as log squared differences and triggered by multipliers $\emptyset = 0$ or 1 according to whether the condition was met.

The Schaefer production model was optimized in R programming code with a Nelder-Mead algorithm (Nash and Varadhan 2011), on both Korean and Spanish CPUE indices and the four penalty functions. The larger number of Korean data automatically gave greater weight to the Korean index. To estimate parameter variability the model was run though a Markov Chain Monte Carlo (MCMC) with 5×10^6 iterations of which the first 20,000 were discarded as burn-in, and every tenth iteration was retained to mitigate autocorrelation. The set of 498,000 retained MCMC iterations was used to generate 95% confidence intervals for each of the optimization parameters K, B_1, r, $q_{Korea\ N}$ and $q_{Spain\ N}$, and for MSY calculated as (Hilborn and Walters 1992):

$$\mathrm{MSY} = \frac{\mathrm{rK}}{4}.$$

Table 1 [next page]. For the fishery north of 51°S latitude*, yearly total skate catches under target license (F/R), yearly total skate catches under other licenses, and standardized skate CPUE index of Korean and Spanish target trawls. Skate target and non-target licenses were not discriminated before 1994.

Year	Catch (tonnes)		CPUE (t/hr)	
	target	non-target	Korean target trawl	Spanish target trawl
1989	812.92		0.33	-
1990	787.03		0.47	-
1991	5806.63		0.39	-
1992	3314.25		0.27	-
1993	5465.51		0.28	-
1994	2186.32	1932.34	0.35	-
1995	3623.42	862.35	0.30	0.09
1996	1927.08	791.01	0.23	-
1997	1976.42	593.86	0.33	-
1998	226.63	396.65	0.42	-
1999	3467.83	417.58	0.38	-
2000	2511.36	549.27	0.33	-
2001	3406.68	542.06	0.40	-
2002	2194.42	495.94	0.44	-
2003	3137.54	479.57	0.43	-
2004	3881.38	473.34	0.43	-
2005	4396.01	594.41	0.51	-
2006	2711.47	1229.93	0.50	-
2007	3527.83	1300.19	0.63	0.45
2008	2280.21	1067.41	0.54	0.49
2009	2932.08	1916.39	0.62	0.62
2010	2725.08	2040.46	0.67	0.44
2011	2572.93	2781.54	0.59	0.34
2012	3094.04	2377.99	0.77	0.60
2013	2223.73	2478.56	0.60	0.39
2014	2953.40	2128.40	0.65	0.84
2015	2365.28	3187.47	0.74	0.38

* Skate-license fishing has been restricted to north of 51°S latitude since 1996. Target catches before 1996, and non-target catches before and since 1996 listed in the table are thus not total catches of skate.

The assessment of total skate biomass can potentially mask changes in assemblage composition, with species more vulnerable to fishing pressure replaced by more resilient species (Dulvy et al. 2000, Ruocco et al. 2012). Agnew et al. (2000), Wakeford et al. (2005), and Winter et al. (2015) examined species composition trends in the Falkland Islands skate fishery. For the current stock assessment, CPUE time-series trends were updated and examined for the six species of interest described in Winter et al. (2015): *B. albomaculata*, *B. brachyurops*, *Z. chilensis*, *B. griseocauda*, *B. multispinis* and *B. scaphiops*. Skate CPUE were calculated from all trawl stations under skate license (or inferred to be skate-targeting prior to 1994; FIFD 2013), north of 51°S, that had observer reports of catch by species. CPUE trends were calculated according to methods slightly simplified from Winter et al. (2015), with CPUE per station GAM-standardized for latitude, longitude, month, depth and nation (Korea or Spain), and the inter-annual trends smoothed using locally-weighted regression (LOESS). Variability of the trends was estimated by randomly resampling with replacement the yearly stations and recalculating the LOESS for each resample. Resampling was iterated 5000× for each species. In several (particularly early) years, some stations recorded various amounts of both identified skate species and the unidentified code ‘RAY’. For these stations the unidentified RAY was then assigned to the identified species as the lesser of either the proportion of identified species among themselves or the ratio of each identified species to the unidentified RAY. The latter option was mainly to prevent large amounts of unidentified RAY being assigned to single identified species at a station. For variability estimation, stations with both identified skate species and RAY were additionally randomized at each iteration by setting the proportional assignment for an identified species to a random uniform draw between zero and 2× the ratio of the identified species to the unidentified RAY (up to a maximum of the total amount of unidentified RAY). Stations that reported only RAY and no identified skate species were excluded altogether as it would be incorrect to record these as having zero catch of any one skate species.

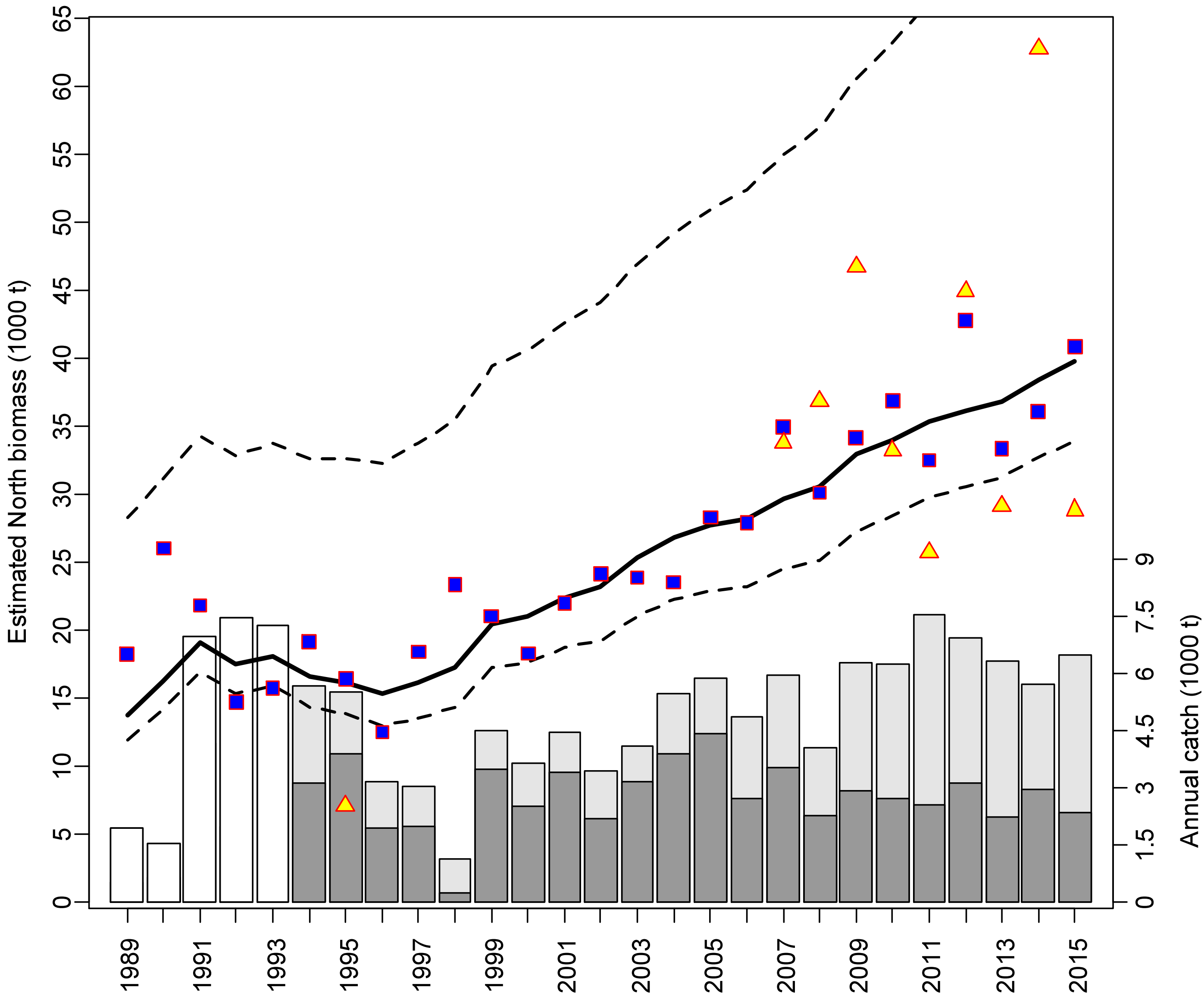

Figure 2. F/R-licensed skate catches (dark grey bars), non-target-licensed skate catches (light grey bars), indiscriminate license catches (white bars), estimated biomass of the northern skate stock ± 95% confidence intervals (black lines), and CPUE indices the biomass time series was optimized on: Korean target trawls (blue squares) and Spanish target trawls (yellow triangles). The figure is formatted for comparison with Figure 3A in Wakeford et al. (2005).

Results

Skate catch north of 51°S was 5552.75 t in 2015, the highest since 1991. While target catch was unexceptional, the non-target skate catch north of 51°S was the highest on record since the start of separate skate licensing in 1994 (Table 1). Total skate catch (north + south) was the third-highest since 1993, after 2011 and 2012 (Figure 2). The proportion of target skate catch vs. total skate catch (north and south) was 36.5% in 2015, a sharp drop from the year before but higher than in 2013 and 2011. The Korean target trawl standardized CPUE in 2015 was the 2nd highest on record after 2012, at 0.74 t hr^{-1}. The Spanish target trawl standardized CPUE (used for the first time in this assessment) included one vessel fishing skate 12 days in 1995, then no fishing effort again until 2007. In contrast to the high Korean CPUE, the Spanish CPUE in 2015 was the second-lowest since 2007 at 0.38 t hr^{-1} (Table 1).

Production model fit parameters for total skate biomass north of 51 ºS are summarized in Table 2 together with their 95% confidence intervals from the MCMC. Notwithstanding the addition of the Spanish CPUE index, a similar outcome as in previous assessments was obtained: very wide bounding of the carrying capacity K and heavily right-skewed biomass estimates. The optimum skate biomass estimate for 2015 was 39,733 tonnes, and the maximum sustainable yield estimate 6,726 tonnes.

Table 2. Optimized Schaefer production model parameters obtained with the combination of Korean and Spanish target trawl CPUE indices, plus resulting estimates of year 2015 biomass north of 51 ºS latitude and MSY. 95% confidence intervals from MCMC iteration of the production model.

Parameter	CPUE target trawl indices	
	optimum	95% conf. int.
K	99,283	80,872 - 1,500,828
B_{1989}	13,780	11,867 - 28,225
r	0.271	0.134 - 0.304
q_{Korea}	1.81 e^{-5}	0.94 e^{-5} - 2.11 e^{-5}
q_{Spain}	1.33 e^{-5}	0.65 e^{-5} - 1.70 e^{-5}
B_{2015}	39,733	33,838 - 81,133
MSY	6,726	5,907 - 60,079

The time series of skate species catch data extended from 1993 to 2015, with data absent in years 1998, 1999, 2005 and 2008 (Table 3). *B. albomaculata* (RAL) and *B. brachyurops* (RBR) continued the increasing CPUE trends that had been noted in Winter et al. (2015), albeit with high variability in recent years (Figure 3). *Z. chilensis* (RFL) CPUE increased consistently through 2013, then followed with two low years in 2014 and 2015. The resulting downturn of the LOESS CPUE trend (Figure 3) was statistically significant by the criterion that a horizontal line would intersect the lower and upper 95% confidence intervals (Swartzman et al. 1992). *B. griseocauda* (RGR) CPUE likewise decreased in 2014 and 2015 to the lowest levels since 2004 (Table 3), but the downturn of the LOESS trend did not meet the criterion of being statistically significant (so far; through 2015, Figure 3). Both of the two less abundant species *B. multispinis* (RMU) and *B. scaphiops* (RSC) had lower CPUE in 2014 and 2015, resulting in a plateau for RMU and a statistically significant decrease for RSC (Figure 3).

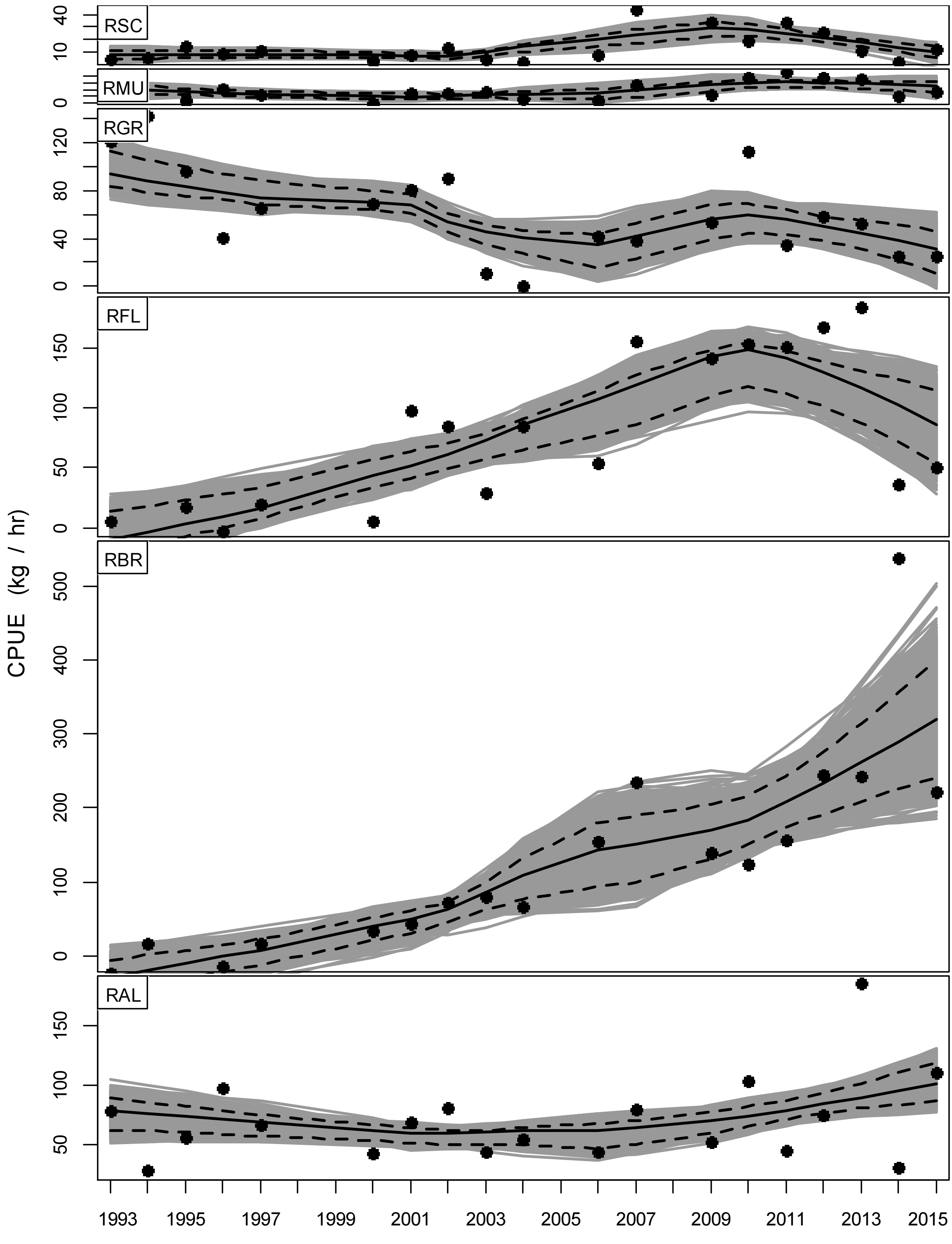

Figure 3. LOESS trends (solid black lines) and 95% confidence intervals (broken black lines) of standardized CPUE by species, 1993 to 2015. Confidence intervals are derived from the randomized iterations (grey lines). Empirical estimates (black circles) correspond to Table 3.

Table 3. GAM standardized CPUE (kg hr^{-1}) per year per species from observer catch data; N = number of observer-sampled stations. Standardized CPUE values correspond to the black circles on Figure 3. Note that the standardization (with residual error added back) resulted in some negative values in some years. These were not corrected, to maintain the relative changes of the inter-annual trends.

Year	N	RAL	RBR	RFL	RGR	RMU	RSC
1989	0	-	-	-	-	-	-
1990	0	-	-	-	-	-	-
1991	0	-	-	-	-	-	-
1992	0	-	-	-	-	-	-
1993	35	78.9	-23.0	5.4	121.8	16.0	4.6
1994	11	28.2	15.8	-18.8	142.5	-9.7	5.8
1995	19	56.5	-33.8	17.2	96.0	2.0	14.6
1996	53	97.6	-14.2	-2.8	40.8	11.0	9.2
1997	60	67.1	16.0	19.4	66.2	6.7	11.4
1998	0	-	-	-	-	-	-
1999	0	-	-	-	-	-	-
2000	76	42.7	33.7	5.6	69.5	0.0	3.4
2001	72	68.6	42.9	97.4	80.5	7.4	8.0
2002	69	80.8	73.1	84.5	90.2	7.5	14.1
2003	54	44.8	79.3	29.4	11.5	8.0	5.5
2004	57	54.8	66.1	84.8	-0.3	3.4	2.9
2005	0	-	-	-	-	-	-
2006	29	44.4	155.6	54.6	41.4	2.2	7.9
2007	35	79.7	235.6	155.6	37.8	13.5	43.4
2008	0	-	-	-	-	-	-
2009	50	52.7	138.6	141.1	54.1	6.4	33.4
2010	57	103.1	123.5	153.9	113.7	19.0	19.9
2011	55	45.2	155.9	151.3	34.5	22.8	34.2
2012	70	75.2	244.0	167.9	58.6	18.5	26.6
2013	33	184.7	242.1	184.5	52.2	18.1	11.3
2014	29	30.6	539.1	37.0	25.3	5.5	2.7
2015	43	111.0	221.2	51.0	24.7	8.6	12.6

Conclusions

Total skate CPUE in the commercial skate-target fishery continued to show an increasing trend in 2015, ongoing since 1996 (Figure 2). The resulting lack of contrast in the time series obtained an imprecise optimization of the Schaefer production model, particularly for carrying capacity K (Table 2). Carrying capacity may be especially unstable in a production model as cumulative changes in reproductive parameters, juvenile and adult survival, growth, and predator and prey interactions contribute to fluctuations in carrying capacity over time (Quinn 2003). However, the optimum model parameters and MSY estimate of this assessment were generally similar to previous years' estimates (e.g., FIFD 2015); indicative that total skate biomass in the Falkland Islands zone appears stable. The ratio of catchability coefficients between Spanish and Korean vessels from joint model optimization (Table 2: 1.33 / 1.81 = 0.737) was higher than - but comparable to - the estimate of 0.600 made after the 2013 skate survey (Pompert et al. 2014).

Use of combined CPUE indices for assessment of the multi-species skate assemblage (Wakeford et al. 2005) remains a potential source of error. Maunder et al. (2006) noted that CPUE is not proportional to community abundance if q (catchability coefficient) is not similar for all species being combined. The species with the highest catchability may contribute a greater proportion to the combined CPUE, and represent the population that is most depleted. Given this issue, for the current skate assessment the examination of individual species' CPUE trends was reprised from Winter et al. (2015), with one year's older data (1993) and two years' more recent data (2014-2015). For several species, the CPUE trend is now less positive than indicated up to 2013 (Winter et al. 2015). In particular, the long increasing trend of *Z. chilensis*, a vulnerable species according to the IUCN (Kyne et al. 2007), has reversed. The recovery of *B. griseocauda*, an endangered species (McCormack et al. 2007), appears to have stalled. Continuing surveillance of skate species trends in the Falkland Islands fishery will be required.

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