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REVIEW

Global seabird bycatch in longline fisheries

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ABSTRACT: Bycatch in longline fisheries is believed to govern the adverse conservation status of many seabird species, but no comprehensive global assessment has been undertaken. We reviewed the extent of seabird bycatch in all longline fisheries for which data are available. Despite the many inadequacies and assumptions contained therein, we estimated that at least 160 000 (and potentially in excess of 320 000) seabirds are killed annually. Most frequently caught are albatrosses, petrels and shearwaters, with current levels of mortality liable to be unsustainable for some species and populations. Where realistic comparisons can be made, with data from the 1990s, there is evidence of substantially reduced bycatch in some key fisheries. Reductions stem from decreased fishing effort (especially in illegal, unreported and unregulated fishing in the Southern Ocean), and greater and more effective use of technical mitigation measures, notably in demersal fisheries. However, bycatch problems in other fisheries have also emerged. Current concerns include those with previously unidentified bycatch problems (e.g. Spanish Gran Sol demersal fleet) and those where bycatch was identified, but where persistent data gaps prevented adequate assessments of the scale of the impact (e.g. Nordic demersal fisheries). Future assessments will only achieve greater precision when minimum standards of data collection, reporting and analysis are implemented by longline fishing fleets and the relevant regional fishery management organisations. Those fisheries in which bycatch has been substantially reduced demonstrate that the problem of seabird bycatch could be reduced to negligible proportions by enforced implementation of appropriate best-practice mitigation devices and techniques.

KEY WORDS: Bycatch · Seabirds · Albatrosses · Global · Threats · Marine conservation

INTRODUCTION

Seventeen of the 22 species of albatross are threatened with extinction (IUCN 2010), with the key threat to most species recognised as incidental mortality (bycatch) associated with fisheries (Robertson & Gales 1998). A further 7 species of petrel (*Procellaria* and *Macronectes* spp.) listed under the Agreement on the Conservation of Albatrosses and Petrels (ACAP), face similar threats (ACAP 2009). All of these procellariiform species are extremely wide-ranging, and their distributions overlap considerably with areas targeted by the world's fishing fleets (BirdLife International 2004). Albatrosses and petrels, along with other seabirds, come into conflict with fisheries when they forage behind vessels for bait and fish waste. The incidental mortality of seabirds on longlines was first reported from bird band recoveries in the early 1980s

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(Morant et al. 1983, Croxall et al. 1984), resulting from birds being caught and drowned on hooks while trying to snatch bait as the lines are set (Brothers 1991). More recently, the threat posed by trawl fisheries (whereby seabirds can become entangled in nets during shooting and hauling, or are killed by collision with warp cable as they forage behind the vessel) has also become apparent (Bartle 1991, Weimerskirch et al. 2000, Sullivan et al. 2006). Even in comparison with other seabird species, Procellariiformes are highly K-selected, so increases in adult mortality readily have significant adverse impacts on a population, several times more so than the loss of young birds (Croxall & Rothery 1991, Véran et al. 2007, Igual et al. 2009). However, quantifying the scale of the problem is difficult due to the diverse and remote nature of many of the world's fisheries, the lack of systematic reporting, and the nature of seabird bycatch rates themselves, which can be highly variable. Nevertheless, several reviews have concluded that recent and/or current reported levels of seabird bycatch are demographically unsustainable for the populations involved (Croxall et al. 1998, Tuck et al. 2001, Arnold et al. 2006, Barbraud et al. 2009, Thompson et al. 2009, Rivalan et al. 2010).

Historically, fishermen have had mixed relationships with seabirds. Aggregations of birds have been used to indicate profitable fishing grounds (Crawford & Shelton 1978), whereas catching non-target species, like seabirds, results in time lost through removing dead birds from hooks/nets, and fish catches foregone due to bait loss; these are detrimental to fishing activities and their economic efficiency. There is therefore, at least potentially, a common interest from conservation and fishery management perspectives alike in addressing this problem. In recent years, an effective response has emerged from the increasing variety and efficacy of technical measures designed to mitigate, and even eliminate, incidental catches of seabirds (e.g. Brothers et al. 1999, Bull 2007, FAO 2008, BirdLife International & ACAP 2009). Despite this, there is considerable evidence that many fisheries do not use recommended best-practice mitigation measures (e.g. FAO 2008), which likely results in rates and levels of bycatch which may not have changed substantially since the problem was first identified.

Despite bycatch in fisheries being the main contributory factor influencing the adverse conservation status of many albatross and petrel species, there have been few attempts either to estimate the full magnitude of the problem, or to indicate which data may be sufficiently reliable to provide baselines for future comparisons. While several papers have reviewed seabird bycatch rates in longline fisheries in various regions (e.g. Brothers 1991, Dunn & Steel 2001, Bugoni et al. 2008a, Rivera et al. 2008), only 1 attempt has been made to collate seabird bycatch data from longline fisheries on a global scale (Nel & Taylor 2003). Furthermore, that study focused only on fisheries catching globally threatened seabirds (i.e. those listed on the IUCN Red List in 2000), and did not attempt to estimate an overall global bycatch level. In addition, most of the data available to Nel & Taylor (2003) related to years prior to 2000. Considerable new data have been reported since then, and several new longline fisheries, thought likely to interact with seabirds, have commenced. All this makes a new and comprehensive review very timely. Such a review also needs to provide clear explanations of the interpretations and extrapolations inherent in working with sparse data provided in a wide variety of formats and with highly variable completeness and accuracy.

The present study aims to (1) review published and unpublished seabird bycatch data for longline fisheries worldwide and provide a comprehensive annotated archive of such information for future comparisons; (2) generate new estimates of seabird bycatch (including at a global scale) and compare these with previous reviews; (3) identify reasons for changes and emerging bycatch problems; (4) highlight continuing data gaps; and (5) indicate future challenges and provide recommendations for priority actions.

METHODS

Data on seabird bycatch. We reviewed the available published and unpublished literature on seabird and longline fishery interactions to obtain a comprehensive inventory of the most recent estimates (up to 2009) for seabird bycatch from longline fisheries around the world. All bird species caught on longlines were included in the review.

Where available, bycatch data from several years were combined in order to calculate an average number of seabirds caught per year in each fishery. Where changes in fisheries practice were obvious (e.g. implementation of new mitigation measures), data were selected to reflect the current situation, as far as data availability allowed.

In some cases, extracting relevant data was relatively straightforward. However, in many cases, assumptions, estimations and extrapolations were required. These are described in full in the Supplement (available at www.int-res.com/articles/suppl/n014p091_supp.pdf) for each fishery examined (see Table 1). Two important examples are as follows. Firstly, for fisheries where seabird bycatch rate data (usually expressed as birds per unit effort, BPUE) were reported, but only for a sample of a fishery (a common event), these were scaled up to the level of the whole fishery using the relevant ratio of fishing effort. This assumes that bycatch rates are homogeneous across the areas and times in question. Secondly, for several key fishing fleets, no data are available on seabird bycatch. In those cases where bycatch rates were available from an analogous fishery (in terms of fishing method, target species and geographical area), and data were available on the magnitude and distribution of effort of the fishery in question, an extrapolation was made on this basis.

In order to provide some indication of the accuracy of the estimate of average number of birds killed in each fishery, a range around this figure was derived for as many fisheries as possible. Some sources included estimates of standard deviation or confidence limits around mean seabird bycatch rates. However, many did not or could not provide such estimates, and upper and lower ranges were more commonly available. Where range values were not provided in the source, these were calculated based on the upper and lower BPUE rates reported and the range in fishing effort across years (lower estimate = lowest BPUE × lowest total fishing effort; upper estimate = highest BPUE × highest total fishing effort). Where the required input variables were not available, no range was estimated. For estimating seabird bycatch associated with illegal, unreported and unregulated (IUU) fishing, data were taken from the review by the Marine Resources and Assessment Group (MRAG 2005).

Data reliability. We devised a measure to indicate how reliably the estimated values may reflect the true total seabird bycatch in each fishery. A scoring system was developed to account for the 3 main sources of error observed to occur within the datasets, each of which was scored as 'Poor', 'Medium' or 'Good'. The final classification of reliability was based on the lowest ranking in any of the 3 categories.

(1) Age of bycatch data: 1986–1994 = Poor, 1995–1999 = Medium, 2000–2009 = Good.
(2) Source of bycatch data: all bycatch data derived from another fishery = Poor; bycatch data partially derived from another fishery = Medium; all data derived directly from the fishery in question = Good.
(3) Accuracy: this reflects several different variables as follows: (i) the level of observer coverage from which a bycatch estimate was calculated (<5 % = Poor, 5–20 % = Medium, >20 % = Good), where percent coverage is ideally defined as the proportion of hooks monitored relative to fleet fishing effort, but may also represent the proportion of sets or vessels monitored; (ii) the spatial and temporal extent of the observer coverage from which a bycatch estimate was calculated (low relative spatial and temporal coverage of observer effort = Poor; low relative spatial or temporal coverage of observer effort = Medium; high relative spatial and temporal coverage of observer effort = Good); (iii) the extent of spatial and/or temporal variability in the bycatch rates across the fishery, where known (i.e. high spatial and temporal variability = Poor; high spatial or temporal variability = Medium; low spatial and temporal variability = Good). Given that sources did not always report on all of these sub-categories, the overall score for 'Accuracy' was based on the sub-category into which the majority of variables (i) to (iii) fell. If only 2 sub-categories were reported on and their scores differed, an informed opinion was taken as to which category was most representative of the data source as a whole.

Comparison with previous reviews. Results were compared with the review by Nel & Taylor (2003). Since that study focused only on fisheries catching threatened seabird species (predominantly albatrosses and petrels), it did not cover all the fisheries discussed in our review.

Data verification. Data were split by country and/or region and sent to relevant seabird and fishery experts for review (see 'Acknowledgements').

RESULTS

The results of the review of seabird bycatch in longline fisheries are shown in Table 1. Data were collected on 68 fisheries, and cover those operating in exclusive economic zones (EEZs) as well as the high seas. Extrapolated data are indicated in Table 1 in square brackets. Full notes on how each estimate was derived are provided in the Supplement. In relation to the data reliability score, 15 estimates were scored as having a 'Good' level of reliability, 23 were scored as 'Medium', and 30 were scored as 'Poor' (see Table S1 in the Supplement).

The sum of the estimated average number of seabirds killed in the 68 longline fisheries in Table 1 equals ca. 160 000 seabirds killed globally each year in fisheries for which data are available. The 10 fleets with the highest levels of seabird bycatch are shown in Fig. 1 and include the Spanish hake fleet in the Gran Sol area, the Japanese pelagic tuna fleet in the North Pacific, the Namibian hake fleet and the Nordic demersal fleets. The data reliability score for 9 of the top 10 fleets was 'Poor'.

The sum of the upper ranges of the 68 fisheries equals ca. 320 000 seabirds killed per year. This value is heavily influenced by the Norwegian demersal fleet (estimated average of 6514 birds caught each year, but with an upper range of 101 380 birds yr^{-1}). Other fleets

Table 1. Current levels of seabird mortality associated with longline fisheries worldwide. IUU: illegal, unregulated unreported fishing; EEZ: exclusive economic zone; HS: high seas; IPHC: International Pacific Halibut Commission; IATTC: Inter-American Tropical Tuna Commission; ICCAT: International Commission for the Conservation of Atlantic Tuna; IOTC: Indian Ocean Tuna Commission; WCPFC: Western and Central Pacific Fisheries Commission. Fishery type – D: demersal; P: pelagic. Fishery scale – Ind: industrial; Art: artisanal. Target species: Al: albacore; Ba: bass; Bf: billfish; Bl: bluefish; Bn: bluenose; Br: bream; Co: cod; Do: dolphinfish; Fin: finfish; Gf: groundfish; Gr: grouper; Gu: gurnard; Had: haddock; Ha: hake; Hal: halibut; Hp: hapuka; Ki: kingclip; Ln: linefish; Li: ling; MM: mahi mahi; Rf: rockfish; Sa: sablefish; Sc: scalefish; Sh: shark; Sk: skate; Sn: snapper; SBT: southern bluefin tuna; Sw: swordfish; Ra: ray; To: toothfish; Tu: tuna; Tus: tusk; Wf: wreckfish. Reliability – P: Poor; M: Medium; G: Good. BPUE: birds per unit effort (in birds per 1000 hooks). Fishing effort (FE) is given in hooks yr^{-1} (or %, where indicated). Data in square brackets are extrapolated

Country	EEZ or HS	Location	Fishery type	Fishery active (mo)	Fishery scale	Target species	Mean FE	Range in FE	Observed FE	Mean BPUE	Annual total bycatch	Range in total annual bycatch	FE period	Bycatch data period	Reliability	Source
Angola	Both	S Angola, Benguela Current, S Atlantic	P	All	Ind	Tu, Sw, Sh, Gr, Ln	3500000		0	[0.07]	[245]		2000–2004	2004, 2006	P	Petersen et al. (2007, unpubl.)
Argentina	EEZ	Patagonian shelf	D	All	Ind	To, Ki	[1440000]			0.04	[58]		2009	1999–2001	M	E. Frere (pers comm.), Favero et al. (2003)
Australia	EEZ	Southern and Eastern Australia	D	All	Ind	Sc, Sh	6700000		270166	[0.001]	10		2007	2002–2005	M	Baker & Finley (2008)
Australia	EEZ	Eastern Australia	P	All	Ind	Tu, Bf	8443782		455964	0.0248	[209]		2007	2007	G	Baker & Finley (2008), Lawrence et al. (2009)
Australia	EEZ	Western Australia	P	All	Ind	Tu, Bf	1500000		200000	0.023	50		2004	2004	M	AFMA (2007), Baker et al. (2007)
Brazil	Both	SW Atlantic	P	All	Ind	Sw, Tu	9000000		788446	0.229	[2061]	[324–4878]	2006	2001–2007	M	Bugoni et al. (2008a)
Brazil	EEZ	Itaipava	P	Oct–Feb	Art	Do	497 boats	227–497 boats	40717	0.15		[Max. 9107]	2006	2001–2006	P	Bugoni et al. (2008b)
Canada	EEZ	Gulf of St Lawrence	D		Ind	Gf		[10000–20000 sets yr^{-1}]	5–10%	[0.0072]	[~150]	[~100–200]	2001	2001	M	DFO Canada (2007)
Canada	EEZ	Atlantic	D		Ind	Hal, Ha, Sk			3–10%	0.016	500			1986–1999	M	Cooper et al. in DFO Canada (2007)
Canada	EEZ	Scotia Shelf, Grand Banks	P		Ind	Tu, Sw			3–10%	0.032	1400			1986–1999	M	Cooper et al. in DFO Canada (2007)
Canada	EEZ	British Columbia (IPHC)	D	Mar–Nov	Ind	Hal	7515000		8.1%	[0.0071]	54		1999–2002	1999–2002	M	Smith & Morgan (2005)
Canada	EEZ	British Columbia	D		Ind	Rf	[4146000]		[5.9%]	[0.017]	72		1999–2002	1999–2002	M	Smith & Morgan (2005)
CCAMLR	HS	Convention Area (excl. sub–areas listed below)	D	All	Ind	To	30330900		[43%]	0	0		2007–2008	2007–2008	G	CCAMLR (2008)
CCAMLR	EEZ	French EEZ 58.6 (Crozet)	D	Sep–Aug	Ind	To	4524240		24.6%	0.0305	131		2007–2008	2007–2008	G	CCAMLR (2008)
CCAMLR	EEZ	French EEZ 58.5.1 (Kerguelen)	D	Sep–Aug (excl. Feb–Mar)	Ind	To	21134790		24.6%	0.0585	1244		2007–2008	2007–2008	G	CCAMLR (2008)
Chile	EEZ	NW Patagonia, S Chile, S Pacific	D		Art	Ha	1800000		330632	0.03	[54]		2002	1999, 2002	G	Moreno et al. (2006)
Chile	EEZ	NW Patagonia, S Chile, S Pacific	D		Art	To	19570000	17680000–21460000	88280	0.047	437		2002	2002	P	Moreno et al. (2006)
Chile	EEZ	S Chile, S Pacific	D	Sep–Dec	Ind	To	4137000		1508500	0	0		2006	2006	G	Moreno et al. (2008)
Chile	Both	FAO Area 87	P	Mar–Nov	Ind/Art	Sw	2500000		90000	[0.29]	[725]	517–923	2007	2007	M	Moreno et al. (2007)

(Continued on next page)

Table 1 (continued)

Country	EEZ or HS	Location	Fishery type	Fishery active (mo)	Fishery scale	Target species	Mean FE	Range in FE	Observed FE	Mean BPUE	Annual total bycatch	Range in total annual bycatch	FE period	Bycatch data period	Reliability	Source
China	HS	E Pacific Ocean	P	All	Ind	Tu	43289000		304390	[0.02]	[866]		2003	2003	P	Dai et al. (2006), IATTC (2006)
China	HS	Indian Ocean	P	All	Ind	Tu	35285000		0	[0.00]	[0]		2006	2002–2006	P	Xu et al. (2007), Huang et al. (2008c)
China	HS	W Pacific Ocean	P	All	Ind	Tu	26103000		96070	[0.00]	[0]		2001	2008	P	Dai & Zhu (2008)
Chinese Taipei	HS	Atlantic Ocean	P	All	Ind	Tu	112909000	59799000–160643000	15602000	0.0075	936	634–1364	2002–2006	2002–2006	M	Huang et al. (2008a)
Chinese Taipei	HS	Pacific Ocean	P	All	Ind	Tu	118206000	82978000–145106000	5348000	[0.045]	1660	544–2628	2002–2006	2002–2006	M	Huang et al. (2008b)
Chinese Taipei	HS	Indian Ocean	P	All	Ind	Tu	253412000	197793000–281473000	6407000	0.048	1512	332–3763	2002–2006	2002–2006	P	Huang et al. (2008c)
Faroes	Both	N Atlantic	D	All	Ind	Co, Had, Tus	153106000		0	[0.02]	[3062]	Upper range [10000]	1997–1998	1997–1998	P	Dunn & Steel (2001)
Iceland	Both	N Atlantic	D	All	Ind	Co, Had, Tus	367000000		0	[0.02]	[7340]	Upper range [20000]	2007	1996	P	Dunn & Steel (2001), ICES (2009)
Japan	HS	Mainly south of 20°S	P	All	Ind	SBT	[26361073]		[1607229]	[0.23]	[6299]	[1163–14182]	2006–2007	2006–2007	M	Minami et al. (2009)
Japan	HS	N Pacific	P	All	Ind	Tu, Sw			0		14540			1994–2000	P	Crowder & Myers (2001)
Korea	HS	E Pacific Ocean (IATTC waters)	P	All	Ind	Tu	36345000		51533	[0.02]	[727]		2004–2005	2004–2005	P	IATTC (2006), Moon et al. (2005)
Korea	HS	Atlantic Ocean (ICCAT waters)	P	All	Ind	Tu, Al	670000		0	[0.10]	[67]		2002–2006	2002–2006	P	ICCAT (2008), Huang et al. (2008a)
Korea	HS	Indian Ocean (IOTC waters)	P	All	Ind	Tu	2556115		0	[0.038]	[97]		2002–2006	2002–2006	P	IOTC (unpubl. data), Huang et al. (2008c)
Mediterranean	EEZ	Maltese waters	D	All	Art	Sh	[~1460 fishers]		146 fishers	1.41 $fisher^{-1}$	1220		2006	2006	P	Dimech et al. (2008)
Mediterranean	EEZ	Mediterranean	P	All	Ind	Sw, Tu, Al	19489389		0	[0.0133]	[259]	[40–448]	2002–2006	1999–2000	P	ICCAT (2008), Valeiras & Caminas (2003)
Namibia	EEZ	Benguela Current, S Atlantic	D	All	Ind	Ha	120000000		456000	[0.145]	20200	Upper range 30650	2000–2003	2006	P	Petersen (2008)
Namibia	Both	Benguela Current, S Atlantic	P	All	Ind	Tu, Sw, Sh	2900000	2500000–3500000	>30770	0.07	206		2002–2004	2004, 2006	P	Petersen et al. (2007, unpubl.)
New Zealand	EEZ	NE and SW EEZ predominantly	P	All	Ind	Tu, Sw	3719000		955519	0.196	715	567–883	2006–2007	2006–2007	G	Abraham & Thompson (2009)
New Zealand	EEZ	Campbell Plateau, Chatham Rise	D	All	Ind	Li, Bn, Hp, Ba, NZ Sn	38164000		2344205	0.026	1122	579–1777	2006–2007	2006–2007	M	Abraham & Thompson (2009)
Norway	Both	NE Atlantic	D	Winter	Ind	Had, Tus	[221613000]		760000	0.02	[4432]	[2216–8865]	2007	1996–1999	P	Dunn & Steel (2001), Løkkeborg (2003)
Norway	Both	NE Atlantic	D	Summer	Ind	Had, Tus	[90518000]		[126700]	0.023	[2082]	[1177–101380]	2007	1996–1999	P	Dunn & Steel (2001)
Peru	Both	Ilo, Callao, Salaverry	P	All	Art	Sh, MM	63250000		354222	0.0028	190		2002	2005–2006	P	Pro Delphinus (2006), J. Mangel et al. (unpubl.)
Peru	HS	12–18° S	D	All	Ind	To	[1017868]						2003		P	Goya & Cardenas (2003)
Russia	Both	W Bering Sea, E Kamchatka	D	May–Aug	Ind	Co, Hal, Rf	[69225000]		[2700000]	[0.092]	[6314]		2003–2004	2003–2004	P	Artyukhin et al. (2006)
Russia	Both	Sea of Okhotsk	D	May–Aug	Ind	Co, Hal, Rf	[26219000]		1100000	0.011	[288]		2004	2004–2005	P	Artyukhin et al. (2006)
South Africa	EEZ	Benguela Current, S Atlantic	D	All	Ind	Ha	30000000	15200000–43600000	450000–4000000	0.0075	225	107–327	2000–2006	2000–2006	M	Petersen (2008)

(Continued on next page)

Table 1 (continued)

Country	EEZ or HS	Location	Fishery type	Fishery active (mo)	Fishery scale	Target species	Mean FE	Range in FE	Observed FE	Mean BPUE	Annual total bycatch	Range in total annual bycatch	FE period	Bycatch data period	Reliability	Source
South Africa	EEZ	Indian Ocean (Asian fleet)	P		Ind	Tu	2846000		2846000	0.05	141		2008	2008	G	P. G. Ryan et al. (unpubl.)
South Africa	EEZ	Atlantic Ocean (Asian fleet)	P		Ind	Tu	341000		341000	0.103	35		2008	2008	G	Ryan et al. (2009)
South Africa	Both	S Atlantic, Indian Ocean (domestic fleet)	P	All	Ind	Sw	1300000	800000–2600000	9.8%	0.23	[299]	[176–624]	1998–2005	1998–2005	M	Petersen et al. (2007, unpubl.)
Spain	HS	E Pacific Ocean (IATTC waters)	P	All	Ind	Sw	6496008		2153000	0.04	[260]		2002–2003	1990, 1998–2005	P	Mejuto & Garcia–Cortes (2005), Mejuto et al. (2007a)
Spain	HS	W Pacific Ocean (WCPFC waters)	P	All	Ind	Tu, Sw	[4415260]		1129000	0.032	[141]		2005	1990–2005	P	Mejuto et al. (2007a,b), Lawson (2007)
Spain	HS	SW Indian Ocean	P	All	Ind	Tu, Sw	6546607		531916	[0.0056]	[37]		2006	2004–2005	M	Ariz et al. (2006), IOTC (unpubl. data)
Spain	HS	S Atlantic	P	All	Ind	Sw	2580000		[15602000]	[0.10]	[258]		2002–2006	2002–2006	P	ICCAT (2008), Huang et al. (2008a)
Spain	EEZ	W Mediterranean	P	All	Ind	Sw, Tu, Al	10864660		4786466	0.038	[413]	[33–989]	2000–2008	2000–2008	M	García–Barcelona et al. (2009)
Spain	EEZ	Columbretes Islands, Mediterranean	D and P		Ind	Ha, Br, Sw	4100000		[88812]	[0.425]	[1743]	656–2829	1998–1999	1998–1999	P	Belda & Sanchez (2001)
Spain	EEZ	Gran Sol, SW Ireland	D	165 d yr^{-1}	Ind	Ha, Br	[55860119]		238025	1.008	56,307		2006–2007	2006–2007	P	P. Arcos (SEO/BirdLife) (pers. comm.)
UK	EEZ	Falkland Islands (Islas Malvinas)	D	All	Ind	To	9355201		1693585 [18.1%]	0.002	16	8–24 [8]	2005–2006	2005–2006	M	Falklands Conservation (unpubl.)
UK	EEZ	South Georgia	D	Mar–Jul	Ind	To	16155379		100%	0	0		2008	2008	G	CCAMLR (2008)
UK	EEZ	Tristan da Cunha	P	All	Ind	Tu			0		[164]	[151–177]	1990–1998	1990–1998	P	Cuthbert et al. (2005)
UK	EEZ	Tristan da Cunha	D	All	Ind	Bl	[907454]		100%	[0.09]	[86]		2005–2008	1996–2008	G	N. Glass (pers. comm.)
Uruguay	Both	S Atlantic	P	Jan–Dec	Ind	Sw, Tu, Sh	1186243		648000	0.42	[498]	[130–2942]	2006	1998– 2004	M	Jimenez et al. (2009)
USA	EEZ	Alaska	D		Ind	All Gf (excl. Hal)	265431600			[0.019]	5138		2006	2002–2006	M	NOAA (2006)
USA	EEZ	Alaska	D		Ind	Hal	[35580316]		0	[0.0071]	[253]		2004–2010	1998–1999	P	IPHC (unpubl. data), Smith & Morgan (2005)
USA	EEZ	Alaska	D	All	Ind	Sa			21–52%		[78]			2002–2008	G	Heery et al. (2010)
USA	Both	NW Atlantic, Gulf of Mexico, Caribbean	P		Ind	Tu, Sw, Sh	8160000		4375000	0.027	230	139–333	2002–2006	1992–2004	M	Hata (2006)
USA	Both	Hawaii	P		Ind	Tu	33600000		100%	0.004	125		2005	2005	G	Clemens (2006), Rivera et al. (2008)
USA	Both	Hawaii	P		Ind	Sw	1300000		>20%	0.04	69		2005	2005	G	Clemens (2006), Rivera et al. (2008)
USA	HS	US West Coast	P	Sep–Jun	Ind	Sw, Tu			100%	0.23				2005	G	L. Enriquez (pers. comm.)
IUU	HS	South of 30° S	P		Ind	Tu, Sw					[4533]	[2739–6326]	2001–2002	2001–2002	P	MRAG (2005)

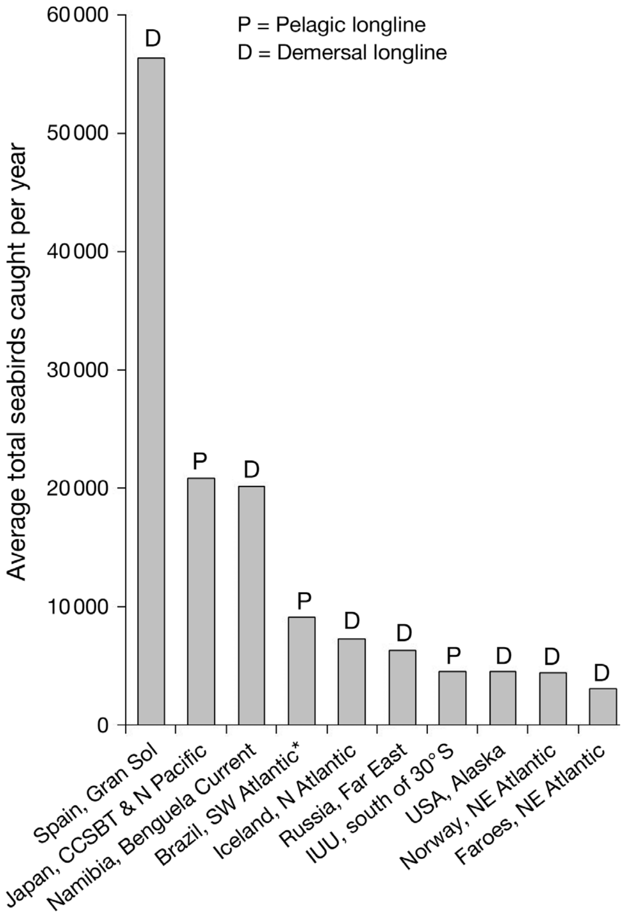

Fig. 1. Fishing fleets with the highest estimated average total numbers of seabirds killed per year. For further details on particular fleets, see the supplement at www.int-res.com/articles/suppl/n014p091_supp.pdf. The asterisk indicates the maximum total seabirds caught per year. Spain: Gran Sol, Northeast Atlantic hake fishery; Japan: Commission for the Conservation of Southern Bluefin Tuna (CCSBT) and North Pacific estimates combined; Namibia: demersal hake fishery; Brazil: NW Atlantic pelagic fishery; Iceland: North Atlantic groundfish fishery; Russia: Far East groundfish fishery; IUU: illegal, unregulated and unreported pelagic longline activity south of 30°S; USA: Alaskan demersal fishery (excluding halibut); Norway: NE Atlantic groundfish fishery; Faroes: NE Atlantic groundfish fishery

with large ranges in estimates include the Icelandic, Faroese, Russian and Namibian demersal fleets.

It was not possible to calculate a lower range of the global estimate of seabird bycatch because of the type of extrapolations required by the data. For example, if a fishery reported variable bycatch rates of 0.00 to 0.44 birds per 1000 hooks, the lower estimate would result in an estimate of 0 bycatch, regardless of any variation in fishing effort.

Sources varied considerably in terms of availability of species-specific bycatch data, and a global estimate of numbers caught by species or species group was not possible. However, the data available indicate that the vast majority of birds caught in longline fisheries were of the albatross (Diomedeidae), petrel and shearwater (Procellariidae) families, along with some species of gulls and terns (Laridae), gannets and boobies (Sulidae) and cormorants (Phalacrocoracidae). Data indicate that northern fulmar *Fulmarus glacialis*, great shearwater *Puffinus gravis* and white-chinned petrel *Procellaria aequinoctialis* are among those caught in the highest numbers, notably in the Spanish (Gran Sol), Nordic, Russian and Namibian demersal fisheries. For fleets operating south of 20°S and in the North Pacific, albatrosses and *Procellaria* petrels form a larger proportion of the bycatch. While these species may be being caught in lower numbers, the impact on their populations may be greater, as a result of their very low reproductive rates and, in most cases, relatively small population sizes. For some of the burrow-nesting petrels and shearwaters, such as the great shearwater, population trends are virtually unknown, and there may be an impact of bycatch on their populations that is currently unrecognised.

DISCUSSION

Scale of global seabird bycatch in longline fisheries

This review indicates that total annual seabird bycatch in longline fisheries is likely to be in excess of 160 000 birds yr^{-1}, and could be as high as 320 000 birds yr^{-1}, based on the average and upper range estimates, respectively, of the longline fisheries for which there are data. It should also be noted that the data reliability score (largely governed by levels of observer coverage) for 9 of the top 10 fleets was 'Poor', the exception being the Alaskan demersal groundfish fleet. It is uncertain whether this would result in bycatch estimates that were typically too low or too high. Nevertheless, the sum of the average estimates is very likely to be conservative, not only due to remaining data gaps (outlined below), but also because observed bycatch rates significantly underestimate actual total bycatch (Gales et al. 1998, Brothers 2008). Brothers (2008) reported only 50% of all birds observed caught during line setting were retrieved when the line was hauled aboard because of dead birds dropping off hooks prior to hauling.

The impact of this loss, on an annual basis, is impossible to assess without detailed species-specific population data. However, previous species-specific studies have assessed bycatch as a threat to relatively common species, such as black-browed albatross *Thalassarche melanophrys* and black-footed albatross *Phoebastria nigripes* (Arnold et al. 2006, Véran et al. 2007). For already highly globally threatened species, such as the Endangered Amsterdam albatross *Diomedea amsterdamensis* and the Critically Endangered Tristan albatross *D. dabbenena*, the impact of bycatch has been highlighted as a driving factor in population declines (Wanless et al. 2009, Rivalan et al. 2010). Greater understanding of species-specific impacts is vital. As an example, the Uruguayan pelagic longline fishery catches many fewer birds than the Spanish Gran Sol fishery. However, albatrosses make up >80% of all seabird bycatch in Uruguay (Jimenez et al. 2009). Many of these birds are wandering albatrosses *D. exulans* from South Georgia, and these losses alone are sufficient to account for much of the continuing (and recently increased) pattern of decline seen in South Georgia wandering albatross populations in recent decades (Croxall et al. 1998, Tuck et al. 2001, Poncet et al. 2006, Phillips et al. 2010).

Comparisons with previous estimates

Full details of comparisons with previous estimates from Nel & Taylor (2003) are provided in Table S2 in the Supplement, and key elements are summarised in Table 2. The comparison highlights changes that have occurred in some fisheries between the mid-1990s and mid-2000s. Where there have been decreases in total numbers of birds caught since Nel & Taylor (2003), the causative factors can be categorised as follows (these categories are also used in Table 2):

(1) Greater or more effective use of mitigation measures;
(2) Changes in fishing practices, particularly using gear or methods less likely to catch seabirds;
(3) Reduction in fishing effort within a particular fleet;
(4) Collapse of a particular fishery as a result of overfishing of target species;
(5) New data available with various and/or unidentifiable causative factors for decrease in bycatch (e.g. varying sample sizes, locations, methodologies).

Where there have been increases in total numbers of birds caught by a fishery, the causative factors can be categorised as follows (categories used in Table 2):

(6) No entry for the fishery in Nel & Taylor (2003) because of an unknown bycatch problem, but new data now available;
(7) No estimate for the fishery in Nel & Taylor (2003) because of a lack of data reportage, but new data now available;
(8) Increase in fishing effort within a particular fleet.

The main fleets for which there have been major decreases in bycatch between the 2 review periods include the following.

Demersal longline fleets operating in Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) waters. Seabird bycatch in the CCAMLR region has decreased substantially in recent years, predominantly due to a decrease in IUU demersal longline activity, which has in turn stemmed from increased enforcement and international policing of the region. The drop in IUU longline activity has led to a reduction in bycatch of ca. 67 000 birds yr^{-1} since the early 2000s. Meanwhile, bycatch in the regulated fisheries has also been substantially reduced, due to the implementation of a comprehensive suite of mitigation measures, including closed seasons (Croxall 2008).

New Zealand demersal ling fleet, South Africa licensed Asian pelagic tuna fleet and the US Alaskan demersal groundfish and Hawaiian pelagic tuna and swordfish fleet. These countries have implemented FAO National Plans of Action (NPoA-Seabirds) (Anon. 2001, 2004, 2008), which require the use of seabird bycatch mitigation measures backed up by observer programs. Comparisons with previous figures for the fleets of these 3 countries indicate a reduction in estimated bycatch of ca. 4000, 17 000 and 15 000 birds yr^{-1}, respectively.

Japanese distant water southern bluefin tuna *Thunnus maccoyi* fleet. The latest estimates point to a potential reduction in total seabird bycatch of ca. 11 000 birds yr^{-1} since estimates from the late 1990s and early 2000s. This stems from (1) a reduction in reported fishing effort from 43 million to 26 million hooks yr^{-1} and (2) a reduction in reported average bycatch rates from to 0.37 to 0.23 birds per 1000 hooks. However, the uncertainty surrounding the new bycatch estimate remains high, with an upper range of ca. 14 182 birds yr^{-1} (Minami et al. 2009).

Uruguayan pelagic industrial fleet for tuna, swordfish and sharks. The total fishing effort for this fleet appears to have declined considerably since the previous estimate (20 million hooks previously, 1.2 million hooks currently). The drop in estimated bycatch from ca. 6000 to ca. 500 birds yr^{-1} reflects this reduction in effort. The upper range on this estimate remains at ca. 3000 birds yr^{-1}.

Brazilian demersal hake and pelagic tuna and swordfish fleets. The collapse of the demersal hake fishery has led to a reduction of ca. 4000 birds killed each year. In the tuna fishery, the estimated number of birds killed per year has also reduced by ca. 4000, in this case as a result of new data and the implementation of mitigation measures. It should be noted that seabird bycatch in the Itaipava fleets is an issue that has emerged since previous estimates, and could amount to up to ca. 10 000 birds killed each year.

These results suggest an overall decrease in seabird bycatch of ca. 127 500 birds killed each year in the fish-

Table 2. Current and previous (Nel & Taylor 2003) estimates of numbers of seabirds killed per year in longline fisheries, with likely causes of change between the 2 periods. CCAMLR: Commission for the Conservation of Antarctic Marine Living Resources; IUU: illegal, unregulated, unreported fishing; IATTC: Inter-American Tropical Tuna Commission; EEZ: exclusive economic zone; WCPFC: Western and Central Pacific Fisheries Commission; UKOT: UK Overseas Territories. Fishery type – D: demersal; P: pelagic. NA: not available. HIMI: Heard and Macquarie Islands. Figures in square brackets are extrapolated from other data. Categories for 'Reason for change' are listed in the 'Discussion'. For further information see Table S2 in the Supplement at www.int-res.com/articles/suppl/n014p091_supp.pdf

Country	Location	Fishery type	Previous estimate	Current estimate	Reason for change
Angola	S Angola, Benguela current, S Atlantic	P	NA	245	6
Argentina	Patagonian shelf	D	1160	[58]	3
Australia	S and E Australia	D	NA	10	7
Australia	E Australia	P	NA	[209]	7
Australia	W Australia	P	NA	[30]	7
Brazil	SW Atlantic Ocean	P	6656	[2061]	1, 5
Brazil	Itaipava	P	NA	[Max. 9107]	6
Brazil	SW Atlantic	D	4214	0	4, 5
Canada	Gulf of St. Lawrence	D	NA	[70–327]	6
Canada	Atlantic	D	NA	500	6
Canada	Scotia Shelf, Grand Banks	P	NA	1400	6
Canada	Pacific	D	NA	54	7
Canada	Pacific	D	NA	72	6
CCAMLR	Convention Area (excl. sub-areas listed below)	D	14050	0	1, 3
CCAMLR	Sub-areas 58.6 and 58.7 (Crozet & Prince Edward Islands)	D	10583[a]	131	1, 3
CCAMLR	Sub-areas 58.5.1 and 58.5.2 (Kerguelen and HIMI)	D	43597[a]	1224	1, 3
Chile	NW Patagonian region, S Chile, S Pacific Ocean	D	NA	[54]	7
Chile	NW Patagonian region, S Chile, S Pacific Ocean	D	NA	437	7
Chile	S Chile, S Pacific	D	NA	0	7
Chile	FAO Area 87	P	NA	517–923	7
China	E Pacific Ocean	P	NA	[866]	6
China	Indian Ocean	P	NA	[0]	6
China	W Pacific Ocean	P	NA	[0]	6
Chinese Taipei	Atlantic Ocean	P	NA	936	6
Chinese Taipei	Pacific Ocean	P	2945	1660	5
Chinese Taipei	Indian Ocean	P	NA	1512	6
Japan	Mainly south of 20ºS	P	[17242]	[6299]	3, 5
Japan	North Pacific Ocean	P	14540	14540	–
Korea	East Pacific Ocean (IATTC waters)	P	NA	[727]	6
Korea	Indian Ocean, south of 20° S	P	NA	[97]	6
Korea	Atlantic Ocean	P	NA	[67]	6
Mediterranean	Maltese waters	D	NA	1220	6
Mediterranean	Mediterranean	P	NA	[259]	6
Namibia	Benguela current, S Atlantic	D	NA	20, 200	6
Namibia	Benguela current, S Atlantic	P	NA	206	6
New Zealand	NE and SW EEZ predominantly	P	NA	715	7
New Zealand	Campbell Plateau, Chatham Rise	D	4958	1122	1, 8
Peru	Ilo, Callao, Salaverry	P	3990	190	5
Peru	12–18° S Pacific Ocean	D	NA	NA	6
Russia	W Bering Sea, E Kamchatcka (Pacific)	D	NA	[6334]	6
Russia	Sea of Okhotsk	D	NA	[288]	6
South Africa	Benguela current, S Atlantic Ocean	D	NA	225	6
South Africa	Indian Ocean (Asian fleet)	P	[17427]	141	1, 3, 5
South Africa	Atlantic Ocean (Asian fleet)	P	as above	35	1, 3, 5
South Africa	S Atlantic, Indian Ocean (Domestic fleet)	P	[354]	[299]	1
Spain	East Pacific Ocean (IATTC waters)	P	NA	[260]	6
Spain	West Pacific Ocean (WCPFC waters)	P	NA	[141]	6
Spain	SW Indian Ocean	P	NA	[37]	6
Spain	S Atlantic	P	NA	[258]	6
Spain	W Mediterranean	P	NA	[413]	6
Spain	Columbretes Islands, Mediterranean	D,P	NA	[1743]	6
Spain	Gran Sol, SW Ireland	D	NA	56307	6
UK	Falkland Islands (Islas Malvinas)	D	40	[16]	1, 3
UK	South Georgia	D	66[a]	0	1, 2, 3
UK	Tristan da Cunha, UKOT	P	NA	[164]	6
UK	Tristan da Cunha, UKOT	D	NA	[86]	6

(Continued on next page)

Table 2 (continued)

Country	Location	Fishery type	Previous estimate	Current estimate	Reason for change
Uruguay	S Atlantic	P	[6000]	[498]	3, 5
USA	Alaska (groundfish)	D	16800	5138	1, 5
USA	Alaska (rockfish)	D	as above	[78]	1, 5
USA	NW Atlantic, Gulf of Mexico, Caribbean	P	NA	230	6
USA	Hawaii (tuna)	P	3268	125	1, 5
USA	Hawaii (swordfish)	P	as above	69	1, 5
IUU	South of 30°S	P	NA	[4533]	6

[a]Estimate comprised of Nel & Taylor (2003) entries for the regions regulated and unregulated (i.e. IUU fisheries) combined

eries listed above, driven both by the use of mitigation measures, changing fishing practices and reduction of fishing effort (Table 2). All of these fisheries overlap with albatross distributions, indicating potentially important reductions in the numbers of albatrosses being caught. However, for some species there remains the possibility that part of any decrease actually reflects diminished populations available to interact with longline fisheries, following a decade or more of unsustainable levels of bycatch. In other words, the proportion of a population being killed as bycatch may remain the same, despite reductions in the total numbers of birds being killed.

Emerging bycatch problems

Progress made towards seabird bycatch reduction in the fisheries listed above is tempered by new information concerning significant bycatch in other fleets. New bycatch data account for ca. 90 730 birds killed each year, all of which was previously unknown and/or unaccounted for in the review by Nel & Taylor (2003), and include the following.

Spanish demersal longline fishery (Gran Sol, North Atlantic). The highest estimated average annual mortality of seabirds in any fishery exists in the Spanish demersal longline fishery operating on Gran Sol, North-East Atlantic (ca. 56 000 birds yr^{-1}), based on data collected in 2006 to 2007. The majority of birds caught in this fishery are great shearwaters, a species not currently believed to have a declining global population (though few, if any, relevant data exist). Nevertheless, the sheer scale of the numbers caught is cause for concern. Further study is required to verify that the bycatch rate is routinely of this magnitude.

Namibian fleets. Seabird bycatch in Namibia did not feature in previous reviews due to an absence of data. The limited information now available points to large numbers of birds being caught by the demersal fleet. Petersen (2008) reported a potential bycatch estimate of ca. 20200 birds yr^{-1}. While the majority of this bycatch is thought to be petrels, albatrosses contribute ca. 600 ind. yr^{-1} to the total, which includes the Critically Endangered Tristan albatross.

Russian Far East demersal longline fishery. Seabird bycatch data from the Russian industrial demersal fleets operating in the Kamchatka region and the Sea of Okhotsk have only become available in recent years. Artyukhin et al. (2006) estimated that ca. 10 000 seabirds were killed in the fishery in 2003 and ca. 2745 seabirds in 2004, resulting in an annual average of ca. 6500 birds killed per year. Species caught include northern fulmar, slaty-backed gull *Larus schistisagus* and short-tailed shearwater *Puffinus tenuirostris*. No mitigation measures were reported in use, and bycatch rates varied considerably, both spatially and temporally. This variation may stem from low levels of observer coverage (3% of total effort in 2003), but could also relate to inter-annual variations in the distributions of seabirds and fishing effort.

Continuing data gaps

Globally, there remain many longline fisheries with insufficient data to assess seabird bycatch. Major data gaps remain for artisanal fleets, such as those in the Mediterranean, West Africa and Northwest Pacific, and many industrial fleets. Some of the main data gaps, for those fleets that have high spatial overlap with vulnerable seabird species, are summarised below.

North-East Atlantic demersal longline fleets. The large uncertainty over seabird (mainly northern fulmar) bycatch levels associated with Norwegian, Icelandic and Faroese demersal fleets in the North Atlantic reflects the fact that the bycatch estimates for all 3 fisheries are based on data collected from the Norwegian fleet over a decade ago. With upper range estimates of annual bycatch nearing 140 000 birds for the 3 fleets combined, it is essential that these fleets be adequately assessed for current bycatch rates, and for true impacts on the relevant seabird populations in the North Atlantic to be characterised. No estimates are currently available for demersal fleets from Greenland or the Barents Sea.

Asian distant water pelagic longline fleets. Significant uncertainty over longline-related seabird bycatch continues in relation to the large Asian distant water pelagic fleets. Data were available from Chinese Taipei fleets fishing in the Atlantic, Indian and Pacific Oceans, but few data were available for the Japanese fleet outside those reported to the Commission for the Conservation of Southern Bluefin Tuna (CCSBT); few data are also available from the Korean and Chinese fleets (see the Supplement).

Mediterranean fleets. Cooper et al. (2003) highlighted the lack of seabird bycatch data available for the Mediterranean. The only rigorous scientific investigations to date have come from Spanish waters in the western Mediterranean (e.g. García-Barcelona et al. 2009). Elsewhere, there are thousands of vessels, mostly artisanal, fishing within the region, yet very little is known of their impacts on seabirds or other vulnerable species. The limited data available indicate that several species of shearwater, namely Balearic *Puffinus mauretanicus*, Yelkouan *P. yelkouan* and Cory's *Calonectris diomedea*, are caught in numbers that may prove to be unsustainable for the potential source populations concerned (Igual et al. 2009). The European Commission has recently taken steps towards an EU Plan of Action-Seabirds to reduce the incidental catch of seabirds in longline and other fisheries, which may stimulate further study of Mediterranean and other poorly documented fisheries within European waters, and may also recommend measures to curb the impact of distant water fleets registered to European states.

Humboldt Current fleets. The Humboldt Current is a particularly important over-wintering ground for several species of albatross that breed in New Zealand, as well as being a key part of the foraging range of the Critically Endangered waved albatross *Phoebastria irrorata* and of several other globally threatened species of *Procellaria* petrels from New Zealand and South Georgia. Bycatch and directed take (intentional hunting) are known to occur in this region, but few data are available to quantify the scale of the problem (Pro Delphinus 2006, Ayala et al. 2008).

IUU fisheries bycatch. Catch rates associated with IUU activity are inherently difficult to assess. Estimates for seabird bycatch in IUU longline fisheries in this review are only for latitudes south of 30° S (MRAG 2005). Although most threatened albatross and *Procellaria* petrel species occur south of 30° S, the potential that significant levels of seabird bycatch continue to occur in IUU fisheries north of this latitude cannot be discounted while such substantial data gaps remain.

Future challenges to improving bycatch estimates

Our review highlights 2 key issues that must be addressed before global estimates of seabird bycatch can be further improved: the lack of observer programs in certain key fleets and/or inadequate spatial and temporal coverage by onboard observer programs; and the need for standardisation in seabird bycatch data collection and reporting.

Increasing coverage by onboard observer programs. A significant number of longline fisheries remain for which no, or very limited, seabird bycatch data are available. Within those fleets, the number of hauled hooks observed is frequently <1% of total fishing effort, and such data as are collected commonly have inadequate spatial and/or temporal coverage of the fleet. To accurately monitor rates of seabird bycatch, observation of ≥20% or more of the hooks may be required (Ashford 2002, Lawson 2006), though in many cases having representative coverage of >5% would be a significant improvement. Sampling strategies must ensure that the observed hooks are spatially and temporally representative of the fishery.

Data collection, analysis and reporting standards. Inconsistencies in the formats of data reported currently hamper our ability to compare seabird bycatch rates between fisheries or over time. Best practice methods for collecting bycatch data have been elaborated (e.g. Dietrich et al. 2007), and establishment of agreed minimum standards for collecting and reporting bycatch data is vital to assist future assessment and mitigation efforts on the catch of non-target species (not just of seabirds), and to ensure transparency for all stakeholders. Based on this review, to allow comparison, reporting should include, at a minimum:

(1) The number of hauled hooks observed per year within the fleet and the proportion of total fishing effort that this represents;
(2) Information on the spatial and temporal distribution of observer effort within the fishery;
(3) The number of birds observed caught (including species identification and status, i.e. dead or alive) and a bycatch rate per thousand hooks;
(4) An estimate of total seabird bycatch along with a stated methodology as to how figures were derived.

CONCLUSIONS

We estimate that at least 160000 birds (with an upper range of 320000 birds) are killed each year in global longline fisheries. However, for almost all current estimates, the absolute levels of seabird bycatch will be substantially higher (by as much as 50%) due to birds killed being unobserved or under-reported. Taking this and other identified data gaps into account, the true global level is likely to be substantially higher.

For those fleets for which seabird bycatch data have been reported, the fisheries with the highest levels of seabird mortality are the demersal fleets of Spain, Namibia, Norway, Iceland, Faroe Islands, Russia and Alaska, the distant water pelagic fleets of Japan and (potentially) the artisanal pelagic fleets in Brazil. The data reliability score for all of the aforementioned fisheries was 'Poor' (with the exception of the Alaskan demersal groundfish fleet, which was 'Medium'), indicating the need for further data as well as implementation of effective mitigation. While demersal fleets have some of the highest levels of bycatch, many pelagic fleets are also important due to the proportion of vulnerable albatrosses and *Procellaria* petrel species caught. Data gaps remain for a number of fleets (especially in the North Atlantic, Mediterranean and Pacific), and these urgently need to be addressed.

As most bycatch estimates, especially at regional and global scales, have considerable associated uncertainties, largely because of persistent fundamental deficiencies in data collecting and reporting, we cannot conclusively determine whether overall levels of seabird bycatch have increased or decreased in recent years. Nevertheless, there are a number of fisheries in which the overall level of estimated seabird bycatch has decreased significantly over the last decade. The single largest reported reduction is of ca. 67 000 birds yr^{-1} in CCAMLR fisheries. Major reductions have also been reported in USA, South Africa and New Zealand fisheries, mainly stemming from the implementation of effective mitigation measures. Reductions are also thought to have occurred in the Japanese southern bluefin tuna fleet and pelagic fleets operating off Uruguay and Brazil, mainly due to reduced fishing effort and some implementation of mitigation measures. These fleets have historically caught large numbers of vulnerable albatross populations, indicating likely important reductions in the number of albatrosses being caught. However, this may still be insufficient to redress population declines if the proportion taken from diminishing populations has not also decreased.

Since Nel & Taylor (2003), emerging bycatch problems have been identified in a number of fleets not previously documented, including the Spanish demersal fishery on Gran Sol (North Atlantic), the Namibian demersal longline fleet, the Russian demersal longline fishery in Kamchatka and the Sea of Okhotsk and (potentially) the artisanal pelagic longline fishery within the Brazilian EEZ. Some of these, such as the Namibian fleet, are also catching high proportions of *Procellaria* petrels and albatrosses. Others in the northern hemisphere are predominantly catching northern fulmars, shearwaters and gulls.

Furthermore, this paper takes no account of bycatch of seabird species (generally of very similar taxonomic composition) associated with trawl or gillnet fisheries, now recognised as contributing substantially to the global bycatch total, particularly in certain regions.

Previous studies have established that bycatch mortality for some seabird species (especially albatrosses and some petrels) is at levels that have potentially serious impacts, and in some cases are clearly unsustainable for known or likely source populations. Numerous seabird species are already globally threatened (sensu Red List Criteria of IUCN 2010), with longline interactions identified as the primary cause of many population declines. Continued bycatch mortality at current levels may well drive them to the brink of extinction.

Key recommendations emerging from this review follow:

(1) All relevant fisheries should implement, to minimum and consistent standards, systematic onboard observer programs to collect and report seabird bycatch information and should make such data available to all stakeholders in a timely and comprehensive fashion. There is an urgent need to collect bycatch data in those fisheries for which data are lacking or current data reliability is deemed 'Poor' (the latter includes 9 of the top 10 fleets identified in this review as having the highest levels of seabird bycatch globally). Regional fisheries management organisations have a key role to play in establishing such standards, notably by implementing the new FAO Best Practice Technical Guidelines for International Plan of Action-Seabirds (FAO 2008). Independently verifiable reduction in seabird bycatch should become one of the indicators of compliance with the UN Code of Conduct for Responsible Fisheries.

(2) Demersal fleets, particularly those in the Atlantic, account for some of the highest levels of current seabird bycatch. Considerable experience in other demersal fisheries indicates that such bycatch can be quickly and substantially reduced (at minimal cost to the fisheries concerned) to levels that pose a negligible threat to populations. The mandatory use of best-practice mitigation measures for the fisheries involved, using only measures of proven efficacy, should urgently be implemented in these fisheries.

(3) Seabird bycatch in a number of pelagic fleets is particularly significant due to the proportion of threatened albatrosses and *Procellaria* petrels being caught. This review has demonstrated substantial reductions in bycatch in some key pelagic fisheries.

Nevertheless, mitigation measures for pelagic fisheries are less well established than those for demersal fleets: some research is underway and more is needed to improve the design of measures such as line weighting and streamers lines. Additional research is needed to facilitate uptake of mitigation measures in these fisheries and to monitor the effectiveness of implementation with a view to adaptive management.

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