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Review

Bycatch in gillnet fisheries – An overlooked threat to waterbird populations

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ABSTRACT

Bird mortality in fishing gear is a global conservation issue and it is recognised that bycatch in industrial longline and trawl fisheries threatens several seabird species. Little is known however about the effects of bycatch in small-scale gillnet fisheries on bird populations. Here we review 30 studies reporting bird bycatch in coastal gillnet fisheries in the Baltic Sea and the North Sea region in order to assess the magnitude of this problem and potential effects on bird populations. All species of diving birds that occur in the study region, including divers (loons), grebes, sea ducks, diving ducks, auks and cormorants, have been reported as dying in fishing nets. The cumulative bycatch estimate extracted from several localized studies providing such information, suggests that about 90,000 birds die in fishing nets annually, a number that is almost certainly a substantial underestimate. We conclude that it is likely that between 100,000 and 200,000 waterbirds are killed per year. Geographic and temporal patterns of bycatch generally matched species distribution and periods of presence. Also, bycatch rates varied depending on species' foraging technique and were influenced by net parameters and fishing depth. To evaluate effects of additive mortality on bird populations, we applied the Potential Biological Removal (PBR) concept to three species with the most extensive bycatch information. Agreeing with PBR assumptions we conclude that bycatch is a matter of concern for at least two of the three assessed species. We suggest that bycatch research in Europe and beyond should aim at unification of principles for bycatch assessment, setting new standards for the monitoring of waterbird populations so that vital rates and mortality data are recorded, and implementing quantifiable criteria for evaluating effects of fisheries bycatch.

Contents

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1. Introduction

Seabird mortality in fishing gear is a globally recognised conservation issue and is believed to be responsible for declines of many bird populations (Tuck et al., 2001; IUCN, 2007). Seabirds get hooked on longlines, become entangled in gillnets, collide with trawler cables, and become trapped in trawl nets and fish traps (Tasker et al., 2000). Globally, the main focus thus far has been on bycatch of Procellariiform seabirds in longline fisheries (Brothers et al., 1999; Lewison et al., 2005), with mortalities in trawl fisheries receiving increasing attention recently (Sullivan et al., 2006; González-Zevallos et al., 2007; Watkins et al., 2008). Although bird bycatch in gillnets has been recognised in many places (e.g., Piatt and Nettleship, 1987; Stempniewicz, 1994; Melvin et al., 1999; van Eerden et al., 1999; Norman, 2000), its magnitude and significance remains largely unknown.

After the ban on large-scale driftnet fishing in the high seas by the United Nations in 1991 (U.N. Resolution 46/215), the majority of the remaining gillnet fisheries are confined to coastal waters and some nations use bottom set gillnets in deep waters. Coastal fisheries are often operated by artisanal fishermen involving a large number of small vessels. Such numerous and diverse fleets that use gillnets in their operations are inherently difficult to monitor. Disparate studies about bird bycatch in these fisheries have not allowed for assessment of population-level bycatch effects thus far.

Sea ducks, diving ducks, divers (loons), grebes, cormorants and auks are abundant in coastal waters and shallow offshore banks of the Baltic and the North Seas in Northern Europe (Durinck et al., 1994; Skov et al., 1995, 2000). Commercial fisheries also operate extensively within the region, and in many coastal and shallow areas there is small-vessel gillnet fishing (James, 2006; ICES, 2007; Ifremer, 2007). The above mentioned birds forage on benthic fauna or fish by diving. If diving birds encounter fishing nets, they can entangle and drown, causing a phenomenon of unintentional catch also called bycatch. Numerous authors have documented bird bycatch in gillnet fisheries in the Baltic and the North Seas. However, the majority of bycatch studies have been small-scale and with limited duration relative to the wintering ranges and generation times of the bird populations affected. Results of some studies suggested that birds experience substantial bycatch mortality within a particular study area (e.g., Kirchhoff, 1982; Stempniewicz, 1994; van Eerden et al., 1999), but such observations have not been translated to a broader scale so far (Tasker et al., 2000; Pihl, 2001; BirdLife International, 2007) and therefore did not provide a comprehensive understanding about the magnitude or population-level effects of bird bycatch in the region or trigger large-scale conservation actions. Nevertheless, it would be unacceptable to ignore the existing evidence and wait until better data become available for addressing the possible problem. Considering the limited resources available for conservation and the substantial costs of comprehensive large-scale bird bycatch assessments, a significant advance in the empirical evidence on this issue is unlikely in the nearest future.

The objective of this study was to evaluate the current state of knowledge about bird mortality in fishing nets in the Baltic and the North Seas by reviewing and summarising all available information. With the exception of Norway and Russia, the countries in our focus region share the EU Birds Directive as the common framework for bird conservation in the European Union (Council of European Communities, 1979). Specifically, we analyse (1) spatial occurrence of bycatch, (2) key bycatch characteristics, (3) potential effects of bycatch mortality on waterbird populations, and we finally discuss (4) what could be done to address this conservation issue.

Although the emphasis of this study is on the Baltic and the North Sea region, the results are applicable far beyond this area wherever the distribution of diving birds and gillnet fisheries overlap in a similar way.

2. Background and material

2.1. Birds inhabiting coastal waters

Numbers of wintering diving waterbirds total at about 8 million in the Baltic Sea and 4 million in the North Sea (Skov et al., 2007). Surface-feeding birds such as gulls, fulmars and gannets, very rarely get entangled in gillnets and consequently were not considered in this review. Also, the artificial coastal Lakes IJsselmeer and Markermeer in the Netherlands regularly support more than 100,000 staging and wintering waterbirds that are susceptible to fisheries bycatch (van Eerden et al., 1999; van Roomen et al., 2006). Most birds occur in large-scale, open waters of our target region during the non-breeding season only. They nest in the boreal forest and tundra zones of Iceland, Scandinavia and northern Russia. Only auks, cormorants and some local sea duck populations are present in the marine environment of our study area year-round. In addition to resident populations, auk numbers increase in winter due to the immigration of birds nesting on island cliffs and rocky shores in the NE Atlantic and Barents Sea.

Several species of diving birds that occur in the region are rare and protected under international agreements. Steller's eider (*Polysticta stelleri*) is listed as Vulnerable by the International Union for Conservation of Nature (IUCN). Red-throated diver (*Gavia stellata*), black-throated diver (*Gavia arctica*), Slavonian grebe (*Podiceps auritus*), Steller's eider and smew (*Mergellus albellus*) are listed in the Annex I of the EU Birds Directive that includes species subject to special conservation measures in Europe (Council of European Communities, 1979).

2.2. Coastal gillnet fisheries

Introduction of synthetic gillnets in the 1960s revolutionized world fisheries by providing inexpensive, long-lasting and easy to handle gear, which comes in great variety of characteristics and configurations (Nédélec and Prado, 1990; Potter and Pawson, 1991). Consequently, gillnets are widely used in small-scale coastal fisheries in the Baltic and the North Seas, with hundreds of small vessels fishing shallow, coastal waters in every country in the region, most prominently in the Baltic Sea (Bos, 2007; ICES, 2007). Gillnet fishermen primarily target cod (*Gadus morhua*), flatfish, herring (*Clupea harengus*), salmon (*Salmo salar*) in the Baltic Sea (ICES, 2007); flatfish and gadoids in the North Sea (Danish Directorate of Fisheries, 2007; Northridge et al., 2007); and pikeperch (*Stizostedion lucioperca*) and perch (*Perca fluviatilis*) in estuaries. Target fish species determine net mesh size and other characteristics, fishing location and depth, which consequently have different effects on bird bycatch.

Developmental trends in gillnet fisheries vary within the Baltic and the North Sea. Commercial fishing in the coastal waters of Estonia, Latvia and Lithuania started in the early 1990s, fishing effort increased rapidly during the following decade and stabilized at current levels (Urtans and Priednieks, 2000; Dagys and Žydelis, 2002; M. Vetemaa unpubl. data). Over this period, use of coastal gillnets apparently increased at the Eastern German and Danish Baltic coasts too (Weber and Bagge, 1996). At the same time, the number of fishermen engaged in commercial fishing decreased in countries of the western Baltic and along the North Sea, partly due to the decline in fish stocks, and partly due to fishery management policies that restricted new entries into the industry and offered incentives for fishermen to change occupations (e.g., monetary rewards for boat scrapping). Boat scrapping programs, however, do not necessarily cause a reduction of fishing effort and thus bycatch of waterbirds. For example, the majority of scrapped boats in Latvia and Poland were pelagic trawlers targeting herring (ICES, 2007), a fishery that has no reported bycatch of birds. On the other hand, the gradual reduction in the number of fishing vessels at Lake IJsselmeer paralleled a fourfold increase in overall fishing effort by the use of gillnets in the 1970s and 1980s (J. de Leeuw pers. comm.). Another recent change in fishing practices is the introduction of longlines at the expense of gillnets in cod fishery in several countries around the Baltic Sea. The proportion of fish landings from longlines, however, remains minor compared to that of gillnets, which continue to be used extensively in coastal waters (ICES, 2007).

Coastal commercial as well as recreational fisheries are poorly monitored, and detailed information on gillnet fishing effort is not available in a comprehensive format, which is especially true for small (<15 m length) fishing vessels (ICES, 2008a,c; Ota and Just, 2008; Pedersen et al., 2009). Measuring gillnet fishing effort is especially challenging, combining as it does a complex mix of length and other characteristics of nets, duration of soak time (rarely recorded), and duration of fishing season.

2.3. Bycatch studies

Bycatch studies can have different design and use varying methodologies (reviewed by Spencer et al., 2001), but they typically seek to answer similar questions: where and when bycatch occurs; what fisheries are involved; what non-target species are affected; how many individuals get killed; whether bycatch is significant in a population context; and if so what could be done to mitigate unwanted fisheries effects. Observed bycatch is usually measured as a bycatch rate, which standardizes the number of birds caught per unit of fishing effort. Having observed bycatch rates for a fraction of the fishing fleet, bird mortality assessment for a particular fishery could be estimated by proportional extrapolation or modelling (Klaer and Polacheck, 1997; Miller and Skalski, 2006). Casual bycatch records cannot be standardized and used for bycatch estimates.

We reviewed all bird bycatch studies from the Baltic and the North Sea region reported since the 1980s. References have been identified querying academic databases (ISI Web of Knowledge, Zoological Record (TM), Google Scholar) and including all bycatch reports, which were cited in scientific publications or were otherwise known to authors of this review. In addition, we included the most recent unpublished results on bird bycatch of own studies.

Although reviewed bycatch studies were conducted over different time periods since the late 1970s, in some instances we pooled the results of different studies for a better understanding of bycatch patterns. While certain changes have occurred in fishing effort (as mentioned above) and waterbird populations (BirdLife International, 2004; Delany and Scott, 2006), these changes have not been substantial so that bycatch patterns would be misrepresented at the scale of this review. We therefore maintain that the reviewed studies are representative and characterise current bird bycatch patterns in the region. Granted, the quality of the reviewed studies differed, however it was not our intention to question the validity of their conclusions. Recognizing inconsistencies in methodologies and study extents, we cautiously used only the most robust and straightforward results, such as measured bycatch rates and bycatch estimates.

3. Bycatch studies in the Baltic and the North Sea region

We reviewed 30 studies reporting bird mortalities in fishing nets across the Baltic and the North Sea region (Table 1, Fig. 1). Bycatch study methods varied greatly resulting in information of different spatial and temporal resolution and units of measurement. The most common approach of investigating bycatch was data collection through cooperative fishermen, who voluntarily provided information about bird bycatch, circumstances of such incidents, and often handed in bird carcasses to investigators. Few studies used fishermen questionnaires, in three instances data were collected by independent observers aboard of fishing vessels and one study investigated bycatch conducting experimental fishing (Table 1, Fig. 1). The studies used varying metrics to record bycatch rates, the most common being the number of birds caught per 1000 m of net length per day (birds/1000 NMD), and, in the absence of true fishing effort data, the number of birds caught by a fishing boat per day or per winter season. Several authors analysed ringed bird recoveries to make inferences about bird mortalities in fishing nets (Table 1). In addition to dedicated bird bycatch studies and analysis of ring recoveries, we reviewed several papers reporting bird mortalities in fishing gear as an additional aspect to their primary focus. Birds identified as having died in fishing nets were reported during beached bird surveys and several records exist of occasionally reported large number of birds drowned in fishing nets (Table 1). Reports of these sporadic bycatch incidents and beached bird surveys were not included into cumulative bycatch estimates reported further in this review, as these studies were not originally designed to assess bird bycatch mortality.

3.1. Bycatch composition and estimates

All diving bird species that occur in the region have been recorded entangled and subsequently drowned in fishing nets (Table 2). Generally, bycatch composition corresponded to species' distribution patterns: sea ducks dominate bycatch in the eastern Baltic, sea ducks and diving ducks – in the southern Baltic; auks, particularly the common guillemot (*Uria aalge*), were most commonly caught in the western Baltic and the North Sea; diving ducks, mergansers, and grebes – in the Lakes IJsselmeer and Markermeer (Table 1). Occasionally dabbling ducks and gulls are caught near the surface but total numbers appear negligible (Žydelis, 2006; J. Bellebaum and F. Erdmann, unpublished).

Several authors estimated bycatch mortalities ranging between 8% and 17% of the maximum counts for certain species in their

Table 1
List of bird bycatch studies in the Baltic Sea and the North Sea mapped in Fig. 1.

No.	Source (type of study [a])	Location	Study period	Bycatch rate	Observed or reported bycatch	Estimated annual bycatch	Affected bird species and their share in bycatch composition
1	Oldén et al. (1988) (Q, VC, R)	South Sweden	1982/83–1987/88	n/a	~750	500–6500	Common guillemot 90%
2	Lunneryd et al. (2004) (Q)	Swedish waters	2002	n/a	2650	18,000	Great cormorant 54% Common eider 14% Common guillemot 11%
3	Fransson and Pettersson (2001), Österblom et al. (2002), and Fransson et al. (2008) (R)	Birds ringed in Sweden	1972–1999	n/a		1500 of common guillemots	Common guillemot Black guillemot Red-throated diver Great cormorant
4	Hario (1998) (R)	Birds ringed in Finland	1926–1993	n/a			Razorbill
5	M. Vetemaa unpublished data (VC)	Gulf of Finland, Estonian coast	2005–2008	0.59 birds/1000 NMD	110	~5000	Long-tailed duck 78%
6	Urtans and Priednieks (2000) (VC)	Latvian coastal waters	1995–1999	n/a	576	2500–6500	Long-tailed duck 38% Divers 16%
7	A. Stipniece and E. Urtans, Stipniece and A. Vaiders unpublished data (VC)	Latvian coastal waters	2000/01–2002/03, 2006/07–2007/08	0.37–0.66 birds/1000 NMD	1224		Long-tailed duck 65% Divers 18%
8	Dagys and Žydelis (2002), and unpublished data, and Žydelis (2002) (VC)	Lithuanian coastal waters	1997/98–2001/03	0.97 birds/1000 NMD	1004	~10% of all birds present (2500–5000)	Long-tailed duck 56% Velvet scoter 16% Divers 7% Steller's eider 6%
9	Stempniewicz (1994) (VC)	Gulf of Gdańsk, Poland	1972–1976, 1986–1990	8–81 birds/boat/winter	1254	17,500 or 10–20% of all birds present	Long-tailed duck 48% Velvet scoter 23% Greater scaup 8%
10	Kieś and Tomek (1990) (VC, Q)	Puck Bay, Poland	1987–1990	3.7 birds/1000 NMD OR 250 birds/boat/year	860	3750	Long-tailed duck 41% Velvet scoter 22% Common guillemot 21%
11	Kowalski and Manikowski, 1982 (VC)	Dziwnów Port, Pomeranian Bay, Poland	1977/78	2.4 birds/boat/day	581	n/a	Long-tailed duck 41% Velvet scoter 22% Common guillemot 21%
12	Schirmeister (2003), unpublished (VC)	Usedom Island, Germany	1989–2005	38.4 (8–186) birds/ fisherman/winter	11,258	3000	Long-tailed duck 74% Common scoter 7% Red-throated diver 7%
13	J. Bellebaum, F. Erdmann, V. Röhrbein, N. Schulz unpublished data (VC, O)	Mecklenburg–W Pomerania coast and lagoons, Germany	2006–2009	n/a	352	n/a	Common eider 14% Tufted duck 14% Pochard 12% Greater scaup 11% Red-breasted merganser 10%
14	Kirchhoff (1982) (VC)	Baltic coast of Schleswig–Holstein, Germany	1977/78–1980/81	5.2 birds/study site/day	2839	15,800 or 17% of all birds present	Common eider 64% Common scoter 18%
15	Grimm (1985) (VC)	Wismar Bay, Germany	1982–1985	n/a		2800 Scaup or 8% of the birds present	Greater scaup Common eider

16	Mentjes and Gabriel (1999) (EF)	Baltic coast around Fehmarn, Germany	1996/97–1997/98	1.2 birds/1000 NMD		n/a	Common eider
17	Christensen (1995) (O)	South central Baltic	1994–1995	n/a	52	n/a	Common guillemot
18	Bregnballe and Frederiksen (2006) (R)	Denmark	1972–2002	n/a		24–66% of ringed birds	Great cormorant
19	Lyngs and Kampp (1996) (R)	Ringed birds recovered in Denmark	1921–1993	n/a			Common guillemot Razorbill
20	Hüppop (1996) (R)	Birds ringed on Helgoland, Germany	1912–1994	n/a			Common guillemot
21	van Eerden et al. (1999) (VC)	IJsselmeer and Markermeer, Netherlands	1978–1990	0.64 birds/1000 NMD (November–March)	10,097	50,000	Tufted duck 25% Greater scaup 23% Red-breasted merganser 17% Great-crested grebe 14%
22	Witteveen and Bos (2003) (VC, O)	IJsselmeer and Markermeer, Netherlands	2002–2003	0.64 birds/1000 NMD	512	12,000	Tufted duck 53% Greater scaup 17% Great-crested grebe 14% Goldeneye 11%
23	Murray et al. (1994) (VC)	NE Scotland	1992	1.4 birds/net/day	323	2400	Common guillemot 71% Razorbill 29%
24	Follestad and Runde (1995) (R)	Birds ringed in Norway		n/a			Great cormorant European shag Common eider Common guillemot Black guillemot
25	Bellebaum and Schulz (2006) (BB)	Mecklenburg–W Pomerania coast, Germany	2006	25% of beached birds with signs of bycatch			Great cormorant Long-tailed duck Greater scaup Goosander
26	Žydelis et al. (2006) (BB)	Coastline of Lithuania	1992/93–2002/03	32% of beached birds died due to bycatch			Long-tailed ducks Divers
27	Meissner et al. (2001) (BB)	Coastline of Poland	1998–1999	77% of beached birds died in fishing nets			Long-tailed duck Velvet scoter Common scoter
28	Durinck et al. (1993) (NS)	North Sea, W Denmark	1987		340		Common scoter Velvet scoter
29	Berndt and Busche (1983) (NS)	SW Baltic	1981				Common guillemot
30	Larsson and Tydén (2005) (NS)	Hoburgs Bank, Central Baltic	1996/97–2003/04		998		Long-tailed duck

[a] Types of bycatch studies: Q – fishermen questionnaire/interview, R – ringed bird recoveries, VC – voluntary collaboration of fishermen, who provided information about drowned birds and circumstances of bycatch, EF – experimental fishing, O – onboard observers on fishing vessels, BB – beached bird surveys, NS – non-systematic observations of bycatch.

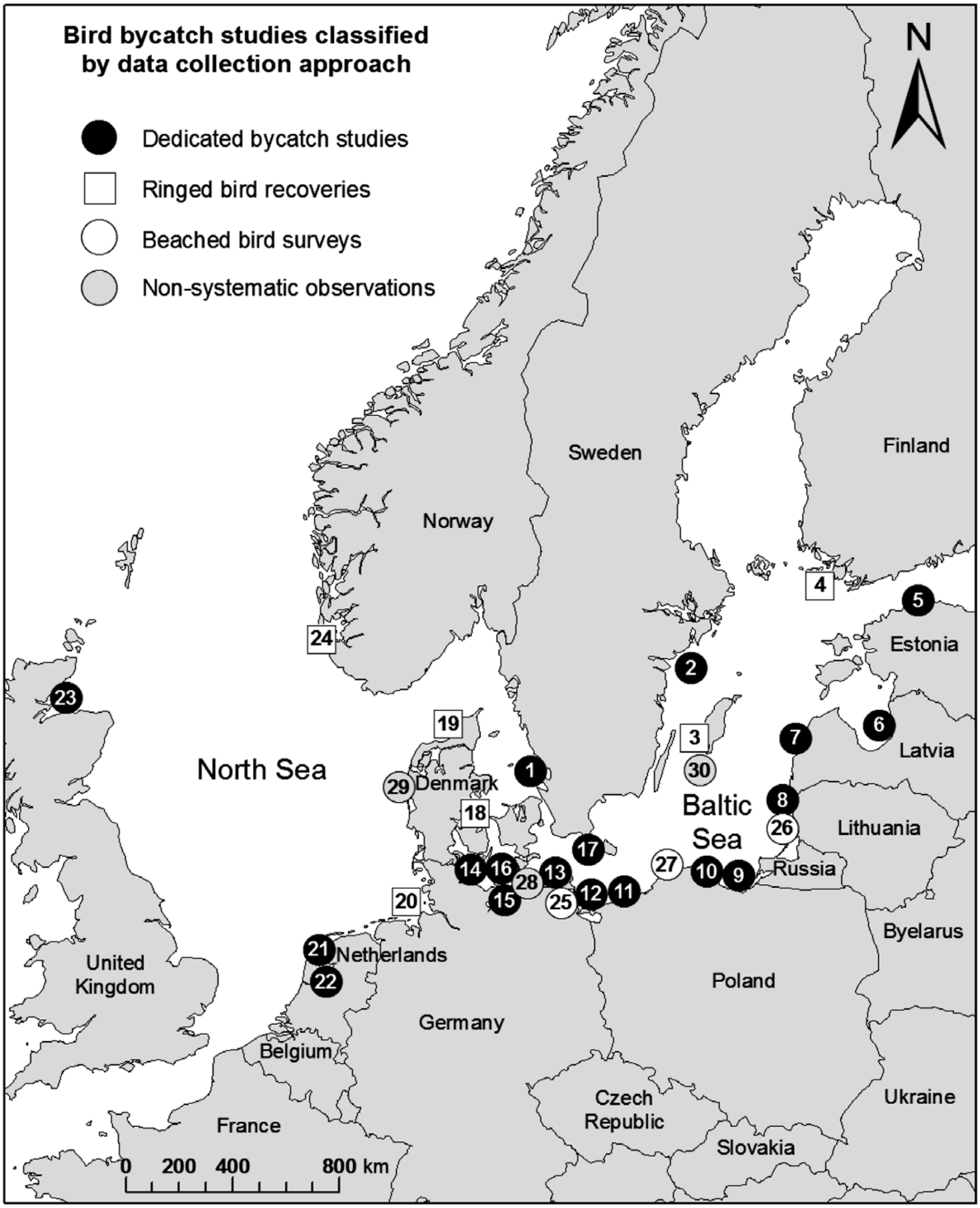

Fig. 1. Geographic location of bird bycatch studies in the Baltic Sea and the North Sea classified by the data collection method (symbol numbers refer to Table 1).

respective study areas in the eastern and southern Baltic (Kirchhoff, 1982; Grimm, 1985; Stempniewicz, 1994; Žydelis, 2002; Table 1). Although no bycatch estimates were provided in some other studies, high numbers of observed bycatch and high bycatch rates imply that fisheries are a considerable source of bird mortality in other locations as well (Kowalski and Manikowski, 1982; Mentjes and Gabriel, 1999; Schirmeister, 2003; A. Stipniece and E. Urtans unpubl. data; Table 1). Ringed bird recoveries also suggest that bycatch in gillnets was an important source of bird mortality in the North Sea at least until the mid 1990s (Follestad and Runde, 1995; Hüppop, 1996; Lyngs and Kampp, 1996). Only a few authors stated that bird bycatch mortality was insignificant in their respective studies (Murray et al., 1994; Hario, 1998).

Lunneryd et al. (2004) estimated that about 18,000 birds drown in fishing nets of Swedish fishermen every year (western Baltic and the Kattegat). Bycatch of common guillemots and razorbills (*Alca torda*) was estimated at 2400 in the NE Scotland (Murray et al., 1994; Table 1). van Eerden et al. (1999) suggested that at least 50,000 waterbirds drowned in gillnets each year between 1978 and 1990 in coastal Lakes IJsselmeer and Markermeer. Seven species annually lost over 1% of their entire regional population in the Netherlands. A more recent study indicated somewhat lower

Table 2
The order of magnitude of reported bycatch estimates and countries with the most frequent bycatch of waterbird species in the Baltic Sea and the North Sea and the respective wintering numbers (from Skov et al., 2007).

Species	Order of magnitude of reported bycatch numbers	Wintering numbers (1987–1995)[a]	Countries with the most frequent bycatch[b]
Red-throated diver *Gavia stellata* and Black-throated diver *Gavia arctica*	Hundreds	>100,000	SE, LV, LT, PL, DE
Red-necked grebe *Podiceps grisegena*	Tens to hundreds	7500	PL, DE
Great-crested grebe *Podiceps cristatus*	Thousands	25,300	EE, LV, LT, PL, DE, NL
Slavonian grebe *Podiceps auritus*	Tens	1850	PL, DE
Great cormorant *Phalacrocorax carbo*	Thousands	33,400	SE, DE, DK, NL
Tufted duck *Aythya fuligula*	Thousands	330,000	EE, PL, DE, NL
Greater scaup *Aythya marila*	Thousands	160,000	PL, DE, NL
Common eider *Somateria mollissima*	Thousands	1500,000	SE, PL, DE
Steller's eider *Polysticta stelleri*	Tens	7000	EE, LT
Long-tailed duck *Clangula hyemalis*	Tens of thousands	4300,000	SE, EE, LV, LT, PL, DE
Common scoter *Melanitta nigra*	Thousands	1353,000	PL, DE
Velvet scoter *Melanitta fusca*	Thousands	1054,000	LV, LT, PL
Goldeneye *Bucephala clangula*	Thousands	139,000	SE, NL
Smew *Mergellus albellus*	Tens to hundreds	17,250	PL, NL
Red-breasted merganser *Mergus serrator*	Hundreds	54,000	SE, PL, NL
Goosander *Mergus merganser*	Hundreds	76,000	SE, EE, LT, NL
Razorbill *Alca torda*	Hundreds	480,000	SE, PL, UK
Common guillemot *Uria aalge*	Thousands	1650,000	SE, UK
Black guillemot *Cephus grylle grylle*	Hundreds	27,500	EE, LT, PL

[a] These estimates do not include birds wintering in IJsselmeer and Markermeer.
[b] No bird bycatch information was available from Denmark, except for great cormorant, Finland, Belgium and France. Country codes: SE – Sweden, EE – Estonia, LV – Latvia, LT – Lithuania, PL – Poland, DE – Germany, DK – Denmark, NL – Netherlands, UK – United Kingdom.

mortality between 10,000 and 15,000 birds per year, a difference which can be explained by lower numbers of birds present in the area, combined with a lower number of gillnets in use (Witteveen and Bos, 2003; Table 1).

Combining available bycatch estimates from different studies in this region, we arrive at a conservative estimate of at least 90,000 waterbirds drowned in fishing nets each year (Fig. 2). While bycatch might have changed in certain locations included in this cumulative estimate, this figure is almost certainly an underestimate of the actual number of birds killed in fishing nets in the Baltic and the North Seas in which spatial coverage was incomplete, markedly so in the case of the North Sea. Gillnet fisheries continue to take place in the areas where estimates of bird bycatch have originated from; there were also no substantial shifts in waterbird distribution patterns over the last decade. Therefore, and because of strong differences within and between seasons, it is not unlikely that the true number of kills is between 100,000 and 200,000 waterbirds per year in the Baltic and the North Seas.

Using available bycatch information, we listed the order of magnitude of annual bycatch for different waterbird species in the Baltic and North Seas (Table 2). The most numerous victim of fisheries bycatch is the long-tailed duck (*Clangula hyemalis*) with a possible annual mortality in the order of tens of thousands. Other sea duck and diving duck species are caught in thousands each year. Anticipated bycatch numbers generally agree with bird abundance in our study region: least frequent among bycatch are rare species, such as Slavonian grebe and Steller's eider (Table 2).

3.1.1. Non-systematic observations of bird bycatch

Although casual bycatch records and reports from non-dedicated studies are of limited use, they still indicate the geography of bycatch occurrence, bird species involved and areas where potential bird-fisheries conflicts are likely.

Results of beached bird surveys in Lithuania indicated that mortalities of at least a third of recovered bird carcasses could be attributed to fisheries bycatch in winters 1992/93–2002/03 (Žydelis et al., 2006). Identified gillnet victims were almost exclusively diving birds, dominated by sea ducks and divers (loons). Drowning in fishing nets was identified as the main cause of bird mortality along the Baltic coast of Poland in 1998–1999, accounting for up to 77% of beached marine birds (Meissner et al., 2001). In the state of Mecklenburg–Vorpommern, approximately 25% of the fresh carcasses of sea ducks and diving ducks showed evidence of or typical injuries from gillnets during February to April 2006 (Bellebaum and Schulz, 2006).

Durinck et al. (1993) reported that a few hundred common scoters (*Melanitta nigra*) and velvet scoters (*Melanitta fusca*) drowned in fishing nets at a single location in the Danish North Sea over a single night. Berndt and Busche (1983) reported that auks are occasionally caught in relatively high numbers in the south-western Baltic Sea, e.g. 60 common guillemots in a small area north of Lübeck in spring 1981. While analyzing the effects of oil pollution on long-tailed ducks at Hoburgs Bank in the central Baltic, Larsson and Tydén (2005) included a sample of 998 birds that drowned in cod nets on 11 occasions over four winters.

3.2. Bycatch characteristics

3.2.1. Seasonal variation

Seasonality of bird bycatch depends directly on temporal overlap of fisheries and bird presence. Clear tendencies could be outlined to characterise the phenology of bycatch in the Baltic Sea and the North Sea. The majority of divers (loons), grebes, sea ducks and diving ducks are present in marine waters only during the non-breeding period, which lasts roughly from October through April (obviously, there is species-specific and latitudinal variation). Therefore, bycatch is highest in winter and during migration.

Only a few local sea duck populations are present year-round. Auks and cormorants are also present in the study region year-round, but during the breeding period the majority of individuals are concentrated around their colonies. There is no information about bycatch of auks and sea ducks during the breeding season, but cormorants get occasionally caught (Bregnballe and Frederiksen, 2006). Also, common scoters return early (July–August) from their northern breeding grounds to moult in the southern Baltic and the North Sea (Sonntag et al., 2004). Late summer moult concentrations of tufted duck (*Aythya fuligula*) and great-crested grebe (*Podiceps cristatus*) were susceptible at Lake IJsselmeer as gillnet

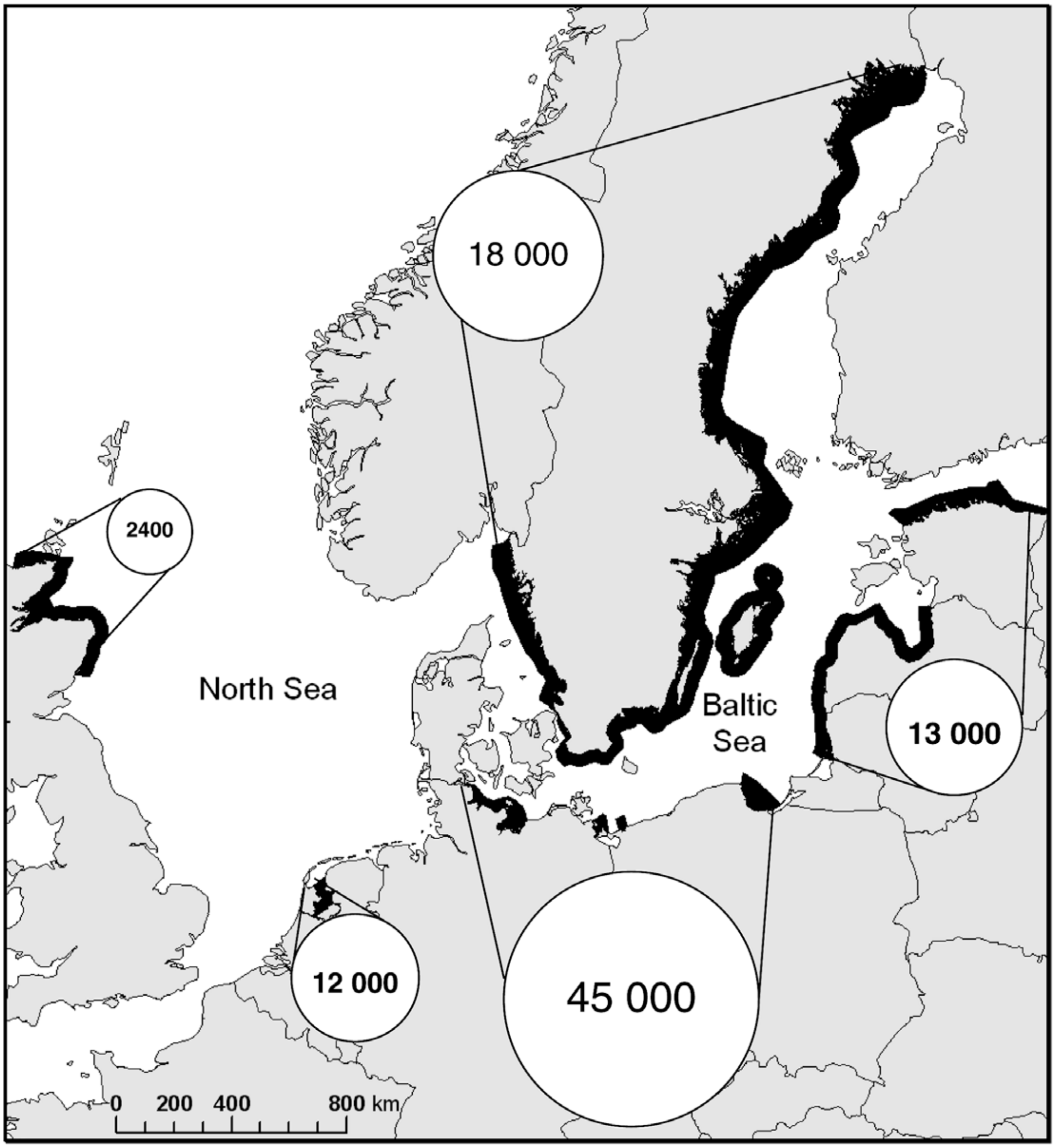

Fig. 2. Cumulative numbers of the total annual bird bycatch estimates available for shaded coastal areas in the Baltic Sea and the North Sea (the most recent figures were used when more than one estimate was available for the same area).

fishery is allowed from 1 July (van Eerden et al., 1999). Consequently, except for these hotspot areas, bird bycatch is very low in large parts of the region in the period from May through September.

3.2.2. Factors affecting bycatch rates

Averaged bycatch rates varied across different locations by a factor of 10 from 0.33 to 3.7 birds/1000 NMD (Table 1). A number of factors could be determining these differences, such as bird abundance and species composition, overlap between bird foraging areas and fishing grounds, fishing gear characteristics, water clarity and also meteorological conditions. Monofilament nylon gillnets result in a greater bycatch than the traditionally used twined nets. Turbid conditions (algae, suspended matter) also increase bycatch rate (van Eerden et al., 1999).

Not all species are equally susceptible to bycatch. For example, comparing species-specific bycatch rates while accounting for species abundance in the study area, Dagys and Žydelis (2002) suggested that divers (loons) are about 10 times more likely to be caught in fishing nets than long-tailed ducks. Similarly, bycatch of two merganser species, smew, great-crested grebe and goldeneye (*Bucephala clangula*) comprised a very high proportion of the maximum numbers of these birds observed in the Lakes IJsselmeer and Markermeer (van Eerden et al., 1999). Some of these differences could arise from turnover of migrating birds. However, in general piscivorous birds, which pursue their prey underwater, are more susceptible to bycatch than benthivorous ducks, which typically dive straight to the bottom and forage on sessile organisms swimming relatively little in a horizontal plane.

Certain net characteristics are also important in determining bird bycatch. Net mesh size differs depending on target fish species and is an important feature affecting bird entanglement. For example, nets with large mesh size (>60 mm knot to knot) set for cod or salmon had about six times higher bird bycatch rates compared to small mesh size nets (18–25 mm) set for herring and smelt on the Lithuanian coast (Dagys and Žydelis, 2002). Net setting depth is also very important: the majority of diving birds prefer shallow waters, and most of the observed bycatch occurred at depths less than 20 m (Stempniewicz, 1994; van Eerden et al., 1999; Urtans and Priednieks, 2000; Žydelis, 2002). Net visibility (thickness and colour), droopiness, height and the number and type of buoys are also characteristics which were found to be important in determining bycatch, although effects of these elements were only qualitatively investigated (van Eerden et al., 1999; Witteveen and Bos, 2003).

4. Population effects of current bird bycatch levels

Once bird mortalities in fishing operations have been estimated, the next essential question is whether observed bycatch is significant. Ideally, we should strive at zero bycatch, but given the economic and social importance of many coastal fisheries, it is more realistic to aim that bycatch at least does not negatively affect bird populations. Currently, there are no guidelines defining bird bycatch limits or other mortality levels that could be deemed as sustainable at either population or geographic scale in Europe. Considering the EU Birds Directive principle requiring to ensure survival and reproduction of migratory bird species (Council of European Communities, 1979), it could be assumed that human-induced bird mortality levels, including bycatch, which exceed intrinsic population growth rates should definitely be treated as unacceptable.

A proper assessment of population dynamics under fisheries impact requires detailed demographic and life history information of the affected species, as well as good bycatch estimates at a regional scale (e.g., Arnold et al., 2006). Unfortunately, population trends are not well established for the majority of the affected species and current population estimates have a limited precision (BirdLife International, 2004; Delany and Scott, 2006). Knowledge about demographic parameters, such as survival rates, reproductive performance, and delineation of population segments is sparse or unavailable for many of the species affected by bycatch in our study region. Finally, discrete bycatch studies, often conducted using different methodologies, complicate the interpretation of localized bycatch effects at a population level. Considering the need for conservation of migratory birds in spite of fragmented knowledge, several recent studies suggested ways to assess bycatch impact on bird populations using limited demographic information (Niel and Lebreton, 2005; Dillingham and Fletcher, 2008; Zador et al., 2008).

One approach is to calculate limits to the allowable human-caused mortality known as Potential Biological Removal or PBR (Wade, 1998). PBR is a threshold of additional annual mortality, which could be sustained by the population, and is calculated with minimal demographic information using the following equation:

$$\mathrm{PBR} = \frac{1}{2} R_{max} N_{min} f$$

where R_{max} is the maximum annual recruitment rate calculated as

$$R_{max} = \lambda_{max} - 1,$$

where λ_{max} is the maximum annual population growth rate. By using N_{min} defined as e.g. the 20th percentile of the population estimate, and the recovery factor f, ranging between 0.1 and 1 the equation acknowledges uncertainty or potential bias in the estimates of population size and growth rates (Wade, 1998; Niel and Lebreton, 2005). Although simple, PBR is a conservative metric and accounts for potential bias due to density dependence, uncertainty in estimates of the population size and stochasticity (Wade, 1998; Taylor et al., 2000; Milner-Gulland and Akçakaya, 2001). Niel and Lebreton (2005) estimated the maximum annual population growth rate for long-lived bird species using only annual adult survival probability s and the age of first reproduction α in the following equation:

$$\lambda_{max} \approx \frac{(s\alpha - s + \alpha + 1) + \sqrt{(s - s\alpha - \alpha - 1)^2 - 4s\alpha^2}}{2\alpha}$$

The main advantage of this approach is that it relies on those demographic parameters which are easiest to obtain for many bird species. The PBR concept is widely used to guide conservation of marine mammals (e.g., Taylor et al., 2000; Marsh et al., 2004) and recently, Niel and Lebreton (2005) and Dillingham and Fletcher (2008) demonstrated its use to assess the significance of bycatch in longline fisheries on seabird populations by comparing mortality estimates to PBR levels. Additive mortality exceeding PBR would indicate potentially overexploited populations and would point out a need for more detailed analysis or management action. Obviously, reliable bycatch estimates are essential, which depend on availability of empirical bycatch observations and good fisheries effort data.

We calculated PBR levels for three species, which are killed as fisheries bycatch in high numbers: long-tailed duck, greater scaup (*Aythya marila*), and common guillemot. Following Dillingham and Fletcher (2008) we set a recovery factor $f = 0.5$ for stable populations, $f = 0.3$ for declining, $f = 0.1$ for rapidly declining.

4.1. Long-tailed duck

Regional (Western Palearctic) population size of the long-tailed duck is estimated at 4.6 million birds and was considered stable (Delany and Scott, 2006). Because this estimate lacks a measure of uncertainty, we assume a coefficient of variation $CV_{\hat{N}} = 0.5$ (Wade, 1998; Dillingham and Fletcher, 2008) to estimate the minimum population size N_{min}. We assumed an age of first reproduction being $\alpha = 2.5$ (Robertson and Savard, 2002). The total long-tailed duck bycatch from available estimates is about 22,000 birds (Kirchhoff, 1982; Kowalski and Manikowski, 1982; Kieś and Tomek, 1990; Stempniewicz, 1994; Urtans and Priednieks, 2000; Lunneryd et al., 2004; B. Schirmeister, M. Dagys, M. Vetemaa and R. Žydelis unpublished data reported in Table 1), which is well below the calculated PBR threshold using a recovery factor $f = 0.5$ (Table 3). Although bycatch estimates are available for only a fraction of the species' wintering areas, it still seems unlikely that

Table 3
Demographic parameter values and calculation of maximum population growth rates and bycatch thresholds (Potential Biological Removal – PBR) for three bird populations in the Baltic Sea Lakes IJsselmeer and Markermeer.

Species	Population min size	Age of first reproduction	Adult survival	Maximum population growth rate		Recovery factor	Potential Biological Removal	
	N_{min}	α	s ± SE	λ_{max}	95% CI	f	PBR	95% CI
Long-tailed duck[a]	3.02×10^6	2.5	0.75 ± 0.16	1.25	1.17–1.30	0.5	189,000	124,000–227,000
						0.3	113,000	75,000–136,000
Greater scaup[b]	204,000	1.29	0.81 ± 0.04	1.36	1.29–1.43	0.3	11,000	8900–13,100
						0.1	3700	3000–4400
Common guillemot[c]	36,000	5	0.97 ± 0.06	1.07	1.06–1.08	0.5	620	520–700

[a] Annual adult survival rate from Robertson and Savard (2002).
[b] Annual adult survival rate and age of first reproduction from Flint et al. (2006).
[c] Annual adult survival rate from Harris et al. (2000).

fisheries induced mortality could pose a population-level impact on this species. However, it should be recognised that PBR estimates apply not only to bycatch, but to all additive mortality. Therefore, we need to consider other known mortality sources as well: annual hunting bag of long-tailed ducks in the countries of the European Union is estimated at 24,000 (Mooij, 2005), while the number of this species hunted in Russia is not known; also, thousands of long-tailed ducks die due to oil pollution every year (Larsson and Tydén, 2005).

Latest reports suggest that numbers of long-tailed ducks have declined in the Baltic Sea (Nilsson and Green, 2007; Kauppinen and Leivo, 2008; Lehikoinen et al., 2008). Under this scenario, applying a recovery factor $f = 0.3$ for the declining population, we calculate PBR = 113,000 (Table 3). Quantified annual bycatch and hunting mortality of the species then sums up to nearly a half of this PBR estimate, which suggests that additive mortality of long-tailed ducks warrants special attention considering that only a fraction of human-caused mortalities is accounted for.

4.2. Greater scaup

The Western Palearctic population of greater scaup is estimated at about 310,000 birds and this species is declining in Europe (Delany and Scott, 2006). Population size is uncertain and therefore we used $CV_{\hat{N}} = 0.5$ to estimate N_{min} (Table 3). Using a recovery factor for the declining population $f = 0.3$, we estimate PBR = 11,000 birds (Table 3). Earlier estimates of bird bycatch in the Dutch Lakes IJsselmeer and Markermeer alone indicated that about 11,600 greater scaup were killed in fishing nets annually during 1980/81–1989/90 (van Eerden et al., 1999). More recent estimates from the same location suggest a lower bycatch of about 2000 birds per year (Witteveen and Bos, 2003). This species also gets caught in high numbers in the southern Baltic (Kirchhoff, 1982; Grimm, 1985; Stempniewicz, 1994; Bellebaum and Schulz, 2006 and unpubl. data). While the cumulative bycatch estimate of about 16,000 birds including figures from van Eerden et al. (1999), which was probably valid for the 1980s and 1990s, exceeded the calculated PBR level, the current situation is less clear. A total estimated bycatch of up to 6500 birds, using figures by Witteveen and Bos (2003), together with a hunting bag of c. 2000 birds in the EU (Mooij, 2005) would indicate that actual mortality is still close to PBR threshold as there are large areas in the southern Baltic with no available bycatch estimates.

BirdLife International (2004) classified the recent status of greater scaup in the EU countries as endangered, due to a large decline recorded during 1990–2000. If we choose a population recovery factor $f = 0.1$, which was suggested for rapidly declining populations, cumulative bycatch estimate from only a part of greater scaup wintering areas, exceeds the PBR threshold of 3700 birds (Table 3), indicating a clear case for conservation concern.

4.3. Common guillemot

We analysed the Baltic-breeding population of about 45,000 common guillemots as a discrete unit which is considered stable (Olsson et al., 2000; Österblom et al., 2002, 2004). The lower limit of the population was estimated at 12,000 breeding pairs, which corresponds to about 36,000 individuals (Olsson et al., 2000; Österblom et al., 2002), and we used this figure as a minimum population size N_{min}. Applying a recovery factor of $f = 0.5$ we estimate PBR = 620 individuals (Table 3). However, estimates of common guillemot bycatch based on observations or questionnaires (e.g., Lunneryd et al., 2004) cannot directly be compared to PBR because they include birds from the North Sea populations wintering in the Kattegat and the western Baltic Sea (Hüppop, 1996; Lyngs and Kampp, 1996).

Using recoveries of ringed birds, Österblom et al. (2002) estimated that about 1500 common guillemots from the Baltic breeding population die in fishing nets annually, provided that all ring recoveries are reported. Anecdotal evidence indicates that far from all recoveries are reported and that the bycatch is thus substantially higher (Österblom et al., 2002). The minimum bycatch estimate of 1500 exceeds the PBR level for this population more than twice, suggesting that bycatch mortality surpasses the level of human impact that could be considered sustainable and may lead to a population decline in the long term. Despite the presumably high mortality the breeding population in the Baltic Sea has been stable or increasing in the main colony during the last decade (H. Österblom et al., unpublished). However, the population may be sensitive to reduced adult survival due to fisheries bycatch and therefore more vulnerable to stochastic events (e.g., avian cholera, Österblom et al., 2004; or oil spills, Olsson et al., 1999).

Further demographic modelling would be needed to evaluate the potential effects of bycatch above PBR on the population. In the Baltic-breeding common guillemot population immature birds are more likely to die in gillnets than adults (Österblom et al., 2002). PBR assumes that all cases of additional mortality are equal and may therefore be too conservative for higher bycatch rates of immature birds.

Similarly, first year cormorants are more likely to get caught in fishing gear than older birds (Bregnballe and Frederiksen, 2006), and the population is thriving in spite of regular human-caused mortality. For most other species little is known about age- or sex-biased bycatch. Adult birds predominate among bycatch of long-tailed ducks and velvet scoters (Stempniewicz, 1994; B. Schirmeister unpubl.) while the situation is less clear for common scoters and greater scaup.

By presenting the examples of PBR application, we demonstrate that fisheries bycatch is a matter of concern for at least two out of three assessed species. While the criteria set for calculating PBR levels could be discussed and re-considered applying more complex demographic models, we believe that PBR represents a viable management tool allowing assessment of fisheries impacts on affected bird populations. PBR thresholds could be readily applied for populations with minimum demographic information while accounting for uncertainty, and PBR estimates are easy to update once new data (i.e., estimates of population size and demographic structure, population trends, and survival rates) become available.

5. Future prospects

All dedicated bycatch studies reviewed here reported substantial bycatch mortality in coastal fisheries across the Baltic and the North Sea region, responsible for deaths of tens of thousands of birds annually. Analyses of ringed bird recoveries, beached bird survey results, and opportunistic bycatch observations indicate that birds also die in fishing nets beyond the areas where dedicated studies took place. Therefore it is obvious that overlapping distributions of diving birds and gillnet fishing create a potential for a conservation conflict, which needs to be assessed and mitigated if bird bycatch appears significant.

Our review showed that the issue had already been recognised around 1980 but since then it was only locally studied and rarely addressed along the coasts of European countries. Owing to a lack of standard methods and sufficient information about fishing effort of coastal fleets, in spite of a number of local studies, we still lack adequate estimates of the number of birds dying in fishing gear; and knowledge about population structure and demography of affected bird species is highly fragmented. European countries have yet to establish management of migratory birds at a population level including measurable criteria about sustainable mortality levels and a framework for conservation action. Finally, fisheries management is primarily concerned with managing target catch rather than fishing effort, which does not stipulate inevitable consideration of fisheries effects on other elements of marine ecosystems.

The EU Birds Directive (Council of European Communities, 1979) outlines requirements to protect rare and migrating species but criteria or standard routines which could help in addressing bird bycatch have not yet been developed. Considering our study area, European Union's protected area network known as Natura 2000 is currently in the process of designation and establishment of marine sites of this network (European Commission, 2007). Following the EU Birds Directive, Member States delineate Special Protection Areas (SPAs) and establish management priorities and conservation measures for birds. If the bird bycatch issue receives sufficient attention, the Natura 2000 network in the marine environment presents an appropriate framework to tackle bird bycatch across European countries. It is up to national authorities and NGOs to identify and highlight wintering hotspots for threatened and declining species in order to focus attention on the SPA network needed to maintain (or restore) favourable conservation status of those species. A good example could be German initiative to consolidate all information on fishing activities in and around marine Natura 2000 sites, review conservation objectives, and identify and address risks (ICES, 2008a,c; Pedersen et al., 2009).

The European Union aims to develop a Plan of Action in 2009 to mitigate seabird bycatch in longline fisheries in EU waters (ICES, 2008b). Our results show that bird bycatch in gillnet fisheries should receive comparable attention and such Plan of Action should address bird mortality in all fishing gears, as already suggested by the experts of the Working Group on Seabird Ecology at the International Council for the Exploration of the Sea (ICES, 2008b).

5.1. Options for mitigating bird bycatch

Although bird bycatch in gillnet fisheries is a widespread phenomenon, examples of successful mitigation measures are scarce, and solutions are likely to be site-specific, depending on fishing practices and bird species involved. Melvin et al. (1999) demonstrated that gillnet modifications increasing net visibility and temporal regulation of fishery effort could decrease bycatch of auks by up to 70–75% without a significant reduction in target fishing efficiency in Puget Sound, USA. van Eerden et al. (1999) proposed different scenarios of spatial and temporal fishery closures, which could substantially reduce bird bycatch in the Dutch Lakes IJsselmeer and Markermeer. Providing buoys with visual bird deterrents was shown to reduce the number of drowned birds (Witteveen and Bos, 2003). Replacing gillnets with longlines was proposed as the most viable solution to decrease sea duck bycatch in the German Baltic Sea (Mentjes and Gabriel, 1999). Longlines, however, might not reduce or even increase mortality in fish-eating birds, thus shifting the problem between species groups. Baited pots are currently being tested as another alternative gear reducing bycatch particularly in cod fisheries in North American waters and in the Baltic Sea (He and Wells, 2005; Ljungberg, 2007). Crucial to the solution of the problem is the willingness of fishermen and authorities to tackle the problem and to promote the co-existence of fisheries and bird populations. This could be achieved by tailoring a fisheries-specific combination of mitigation measures for specific regions.

5.2. Rethinking bycatch research

Sound and consistent knowledge is needed to ensure bird protection and manage fisheries in a sustainable way. Based on our review we suggest the following improvements to guide future work on bycatch:

1. Unified principles and protocols for studying bycatch in small-scale gillnet fisheries would allow for comparison and merging results of different studies. Shared databases could serve as a repository for conservation-sensitive data, as it is unrealistic to expect all collected information to be reported in the primary literature. The grey literature is often written in national languages and has limited accessibility and, therefore, use.
2. There is a need for new standards for monitoring migratory waterbirds, which would allow an understanding of population dynamics and address conservation issues based on sound scientific information, particularly reliable data on recruitment and mortality (Elmberg et al., 2006).
3. Clear criteria outlining sustainable bird bycatch levels would stipulate unambiguous bird mortality assessments and transparent decisions about the necessity for bycatch mitigation. Potential Biological Removal (PBR) could be a good candidate tool for setting such standards.
4. Under the legislation of the European Union, species management plans give an opportunity to implement a practical response to such quantitative criteria, and management of the protected area network Natura 2000 should consider bird bycatch as an important issue.

5.3. International context

Bird bycatch in coastal fisheries is not unique to Northern Europe. Many coastal waters around the world hold large concentrations of waterbirds and are also used by small-scale gillnet fisheries. Publications indicate that bird bycatch is especially prevalent across the northern hemisphere where abundant diving seabirds inhabit coastal waters (Bakken and Falk, 1998). To name a few, eider mortality in gillnets was reported from Greenland (Merkel, 2004), high numbers of common guillemots and shearwaters die in fishing nets off Newfoundland and Labrador (Davoren, 2007; Benjamins et al., 2008), auks entangle in salmon nets on the Pacific coast of North America (Melvin et al., 1999), hundreds of thousands of seabirds die in salmon nets in Russian Exclusive Economic Zone of the Pacific Ocean (Artyukhin and Burkanov, 2000). Birds drowning in gillnets have also been recorded along the coasts of South America (Simeone et al., 1999; Majluf et al., 2002), Australia (Norman, 2000), and New Zealand (Darby and Dawson, 2000). Gillnet fisheries have been shown having detrimental effects on localized seabird populations in the past (Vader et al., 1988; Takekawa et al., 1990; Strann et al., 1991).

Effects of small-scale fisheries deserve closer attention worldwide, as it is possible that impacts on seabird populations are under-assessed or overlooked. As most of the affected populations are migratory, internationally co-ordinated approaches are important. Our suggestions on using unified bycatch assessment principles, monitoring demographic parameters of bird populations and implementing quantifiable criteria for bycatch management, are likely to hold promise beyond our study region and should help improving knowledge about bycatch and assisting management of small-scale fisheries.

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