Birds in estuaries can act as indicators of climate change: a study at a key wintering site for waterbirds in Europe

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Climate change can shift the winter range of many species and birds can act as indicators of this process. Estuaries of large rivers are places where different waterbirds winter with each species reflecting their own behavior and sensitivity to weather changes. Knowing these behaviors and tracking long-term changes in the number of birds, we can confirm the direction of climate change. One estuary of key importance for wintering waterfowl is the Odra River Estuary situated in the south-western part of the Baltic Sea. The most numerous birds here belong to two groups: benthic feeders and fish feeders. We show that numbers of all benthivorous waterbirds were negatively correlated with the presence of ice, but for piscivorous there was no relationship. We anticipate that with continued global warming the importance of this area for benthic feeders will increase, but will decrease for fish feeders. Among the seven species of benthivorous birds we studied, one showed an increase in numbers (Greater Scaup *Aythya marila*), two were stable (Tufted Duck *A. fuligula* and Eurasian Coot *Fulica atra*) and two decreased (Common Pochard *A. ferina* and Common Goldeneye *Bucephala clangula*); among the piscivorous group two species (Smew *Mergellus albellus* and Goosander *Mergus merganser*) showed a decline. The decline of the Common Pochard may reflect that species global decline. Climate change may be responsible for some of the local changes in the study area, namely the increase in the number of Greater Scaup and reduction in the numbers of Common Goldeneye, Smew and Goosander.

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Birds in estuaries can act as indicators of climate change: a study at a key wintering site for waterbirds in Europe

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Abstract

Climate change can shift the winter range of many species and birds can act as indicators of this process. Estuaries of large rivers are places where different waterbirds winter with each species reflecting their own behavior and sensitivity to weather changes. Knowing these behaviors and tracking long-term changes in the number of birds, we can confirm the direction of climate change. One estuary of key importance for wintering waterfowl is the Odra River Estuary situated in the south-western part of the Baltic Sea. The most numerous birds here belong to two groups: benthic feeders and fish feeders. We show that numbers of all benthivorous waterbirds were negatively correlated with the presence of ice, but for piscivorous there was no relationship. We anticipate that with continued global warming the importance of this area for benthic feeders will increase, but will decrease for fish feeders. Among the seven species of benthivorous birds we studied, one showed an increase in numbers (Greater Scaup *Aythya marila*), two were stable (Tufted Duck *A. fuligula* and Eurasian Coot *Fulica atra*) and two decreased (Common Pochard *A. ferina* and Common Goldeneye *Bucephala clangula*); among the piscivorous group two species (Smew *Mergellus albellus* and Goosander *Mergus merganser*) showed a decline. The decline of the Common Pochard may reflect that species global decline. Climate change may be responsible for some of the local changes in the study area, namely the increase in the number of Greater Scaup and reduction in the numbers of Common Goldeneye, Smew and Goosander.

Key words: winter range shift; ice coverage sensitivity; Greater Scaup; Tufted Duck; Common Pochard; Eurasian Coot; Smew; important bird areas; behavior; Baltic Sea

Introduction

Climate change shifts the winter range of many bird species (Musil et al. 2011; Meller 2016). Knowing the behavior of species we can track changes in population numbers which may reflect changes in temperatures. The migration distance of southern and western European species to wintering areas in central Europe are shorter during mild winters (Pavon-Jordan et al. 2015). It is advantageous for populations to have short migration distances since this behavior allows early arrival to breeding grounds, acquisition of higher quality territories, and probably greater survival (Coppack and Both 2002; Jankowiak et al. 2015a; 2015b). Bird may change their wintering sites to warmer regions during colder periods because they can sense the local manifestation of large-scale atmospheric features (Newton 2008). The food resources of wintering sites are also a factor in decisions about staying at potential sites (Cresswell 2014; Aharon-Rotman et al. 2016). However the winter site fidelity of waterfowl is known to be very high (Newton 2008), but site fidelity can decrease because of changes in weather, climate, habitat and competition (Cresswell 2014). The changing of winter sites should be seen as trade off between the costs of finding new sites and the benefits available at the new site (Aharon-Rotman et al. 2016). Here we tested changes in wintering sites by waterbirds as a result of climate changes. The shallow water of nearshore lagoons create ideal conditions for three functional ecological groups of waterbirds: piscivores, herbivores and benthivores. In our study, benthivores included Greater Scaup (*Aythya marila* – hereafter Scaup), Tufted Duck (*A. fuligula*

– hereafter Tufted Duck), Common Pochard (*A. ferina* – hereafter Pochard), Common Goldeneye (*Bucephala clangula* – hereafter Goldeneye) and Eurasian Coot (*Fulica atra* – hereafter Coot); and piscivores included Smew *Mergellus albellus* and Goosander *Mergus merganser* (Kaliciuk et al. 2003; Czeraszkiewicz et al. 2004; Marchowski and Ławicki 2011; Guentzel et al. 2012; Marchowski and Ławicki 2012; Marchowski et al. 2013). The study site is known to hold on regular basis significant number of a biogeographic population of the above listed species (Wilk et al. 2010) (see Table 3). Biogeographic population in this work means the part of global population with specific flyway region eg. in the case of Scaup the population breeding in western Siberia and northern Europe and wintering in western Europe (according to Wetland International 2016). The Odra River Estuary accommodates large numbers of waterbirds because of food resources (Marchowski et al. 2015; Marchowski et al. 2016). The study area is recognized as an Important Bird Area (IBA) of international importance and designated also as Natura 2000 areas of the European ecological network. Changes in the structure of species proportions and their numbers at the Odra River Estuary over the years may show the impacts of climate change.

In this paper we are asking questions about whether some species, due to climate warming, will change their presence at the Odra River Estuary. We assumed that benthic feeding birds will be more sensitive to ice cover and that fish feeding birds will not be affected by ice cover. If our assumptions are true, increased temperatures and the corresponding shorter period of ice cover provide better conditions for benthic feeders and their numbers may increase. Most of the richest feeding grounds rich in mussels are located in shallow water (Marchowski et al. 2015), so any ice cover significantly reduces the availability of food. Fish, on the other hand, remain available even when ice cover is great since unfrozen areas may still be rich in fish.

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Study area

The study area lies in the south-western part of the Baltic Sea and forms the Polish part of the Odra River Estuary system, which includes the Great Lagoon (Polish part of the Szczecin Lagoon), Świna Backward Delta, Kamień Lagoon, Dziwna Strait and Lake Dąbie with a total area of 522.58 km^2 (Fig. 1). Average and maximum depths of the estuary are 3.8 and 8.5 m, respectively; the dredged shipping lane cutting across the estuary from the Baltic Sea to the port of Szczecin is 10.5 m deep (Radziejewska and Schernewski 2008). Waters of the Szczecin Lagoon, Kamień Lagoon and Lake Dąbie are brackish. The salinity in the central part of the estuary varies from 0.3 psu to 4.5 psu (mean = 1.4 psu) and declines with increasing distance from the sea (Radziejewska and Schernewski 2008). Periodic inflows of water from the Pomeranian Bay (salinity ~7 psu) take place through the Świna Strait and, to a lesser extent, through the Dziwna and Peene Straits (the latter located in the German part of the Odra River Estuary). Average winter temperature is 0.3° C (Weatherbase 2016). The Odra River Estuary is subject to strong anthropogenic pressures manifested by high levels of eutrophication with all its adverse effects (Radziejewska and Schernewski 2008). Communities of benthic organisms are typical of freshwater bodies and the fauna includes large populations zebra mussels *Dreissena polymorpha* which were introduced in the mid-19th century. By the 1960s, the biomass of zebra mussels in the Szczecin (Great) Lagoon was estimated at 110,000 metric tons (Wiktor 1969, Wolnomiejski and Woźniczka 2008) and has seemed to be quite stable; biomass estimate from the early 2000s was 94,280 metric tons (Marchowski et al. 2015). The fish fauna consists mainly freshwater fish such as roach *Rutilus rutilus*, bream *Abramis brama*, pike *Esox lucius*, perch *Perca fluviatilis*, ruff *Gymnocephalus cernua*; there are also anadromous fish like smelt *Osmerus* *eperlanus*, as well as endeavoring to inflows of sea fish like herring *Clupea harengus* (Wolnomiejski and Witek 2013).

Methods

Birds census

Censuses were conducted using standard methods for non-breeding season waterbird counts (Komdeur et al. 1992; Wetland International 2010). Birds were counted during 17 seasons (1991/1992 to 1993/1994 and 2001/2002 to 2015/2016) during migration and wintering periods between November and April. Three censuses were made per season during November, January and March or April; during 1991/1992 to 1993/1994 and for 2001/2002 only a mid-winter count in January was made. All together we analyzed 43 count results. Most counts were conducted on foot. Each observer was equipped with 10x binoculars and tripod-mounted telescopes. Observers walked along the same routes stopping every few hundred meters or conducted observations from vantage points reachable by car. Thirteen aerial counts were made at average speed of about 100 km/h and about 80 m above the water. Bird locations were plotted using an onboard GPS device. Detailed methodology and results of these counts are given elsewhere (Meissner and Kozakiewicz 1992; Meissner et al 1994; Kaliciuk et al. 2003; Czeraszkiewicz et al. 2004; Marchowski and Ławicki 2011; Guentzel et al. 2012; Marchowski and Ławicki 2012; Marchowski et al. 2013). Counts of large numbers of unidentified *Aythya* species -in November 2009 (26,000 individuals), November 2010 (13,000 individuals), January 2012 (6000 individuals), March 2012 (3300 individuals), and November 2015 (13,500 individuals) - were allocated to either Greater Scaup or Tufted Duck based on the mean ratio of these two species (1.0 Scaup : 0.8 Tufted Duck) obtained from other counts. The research consisted of observations of birds from a distance, such studies do not cause disturbance of birds. In Poland, such studies do not need special permission or approval.

Ice cover data

We used data on ice cover as published by the Polish Institute of Meteorology and Water Management. These data were collected using standard methods specified for the entire basin of the Baltic Sea partitioned into sectors. Ice conditions of each sector were contained in the "Monthly Ice Listing" daily protocol encoded as a four-digit key $A_BS_BT_BK_B$ where A_B is the degree of ice cover and placement of ice, S_B is the stage of development of ice, T_B is topography and type of ice and K_B is the conditions for navigation in ice. In addition to the information contained in the key, we recorded ice extent (km), ice thickness (cm), thickness of snow on the ice (cm), direction and speed of ice, range of visibility of water body surface (km). The observation point at Miroszewo on the shore of the Szczecin Lagoon (53.734 N, 14.331 E) is one of the stations included in the ice information system of the Baltic Sea region. The point was located at the top of a cliff, above the water surface and on a clear day about 75% of the surface of the Szczecin Lagoon, the largest water body in the Odra River Estuary, can be seen. Observations were conducted daily from 1 November to 30 April at 12:00 UTC.

Statistical analysis

For statistical calculations, we used ice cover data for the date prior to the bird count. We compared the number of days with 100% ice cover in the period from 0 to 15 days prior to bird counts. Ice cover of 100% refers specifically to the observation point but our field observations show that most of our study area is also nearly 100% frozen. In practice, however, 100% of ice cover never occurs (Girjatowicz 1991; 2005; see also Discussion section for explanation) and birds are still be present in these conditions. Our count data was compared to a species' biogeographical population. Using population estimates and trends (Wetland International 2016 after: Larsen 1992; Delany et al. 1999 and BirdLife Inernational 2004; see Table 1) we calculated the percentage of the total population represented by our counts. The population size for each of winter season was corrected by changes from year to year, e.g., the in case of Scaup, total population in 1991 was 310,000 and assuming a 2.3% annual decline the 1992 population was 303,000 and then 296,000 in 1993 and so on. So our dependent variable reflects the change to whole regional population.

To check the relationship between percentage of population of given species and ice cover we performed a generalized mixed model. The target variable was treated with normal distribution response distribution and identity link function. Mixed models allowed us to have repetition across survey years (random intercept). Both independent variables were continuous. Before starting the analysis we tested variation inflation factor between continuous variation, and analysis showed no collinearity between them. We used the statistical software R (R Core Team 2014) with installed package lme4 (Bates et al. 2014) for analyses. $P < 0.05$ was considered as statistical significant.

Results

Results confirmed our suspicions that the benthic feeding species were more sensitive to lower temperatures and leave sooner when colder weather creases ice cover, while fish feeding species do not show changes in their numbers regardless of ice cover (Tables 2).

Additionally results show changes in the population numbers over the last 25 years. In the case of Scaup we found an increase in their numbers at the Odra River Estuary despite a general decline for the species wintering in northern and western Europe. Tufted Ducks showed no changes at the Odra River Estuary while numbers wintering in north-western Europe increase slightly. Pochards showed declines in their relative number in our study area as well as for northern Europe in general. For Goldeneye we noted a decline in the Odra River Estuary, but for Europe populations increased. The relative number Coots did not change in the Odra River Estuary while European numbers decreased slightly. Smew showed a decrease in the Odra River Estuary while European numbers increased. Goosander numbers decreased in the Odra River Estuary and showed a slight decrease for population wintering in north-western and central Europe (see Table 1, Table 2 and Wetland International 2016). Changes in the importance of the Odra River Estuary for wintering populations of diving waterbirds in the last 25 years occurred for five of the seven species we studied. Tufted Duck and Coot did not have significant changes. For Scaup we noted the growing importance of the area and for Pochard, Goldeneye, Smew and Goosander a decrease (Table 3).

Discussion

As we predicted benthic feeding birds (Scaup, Tufted Duck, Pochard, Goldeneye and Coot) were more sensitive to the presence of ice cover. Benthivorous birds feed in the Odra River Estuary mainly on mussels from the genus *Dreissena* (Marchowski et al. 2015, 2016), these food resources are primarily found in water 1-2 m deep (Wiktor 1969; Wolnomiejski and Woźniczka 2008; Wolnomiejski and Witek 2013). Shallow water freezes faster displacing birds to deeper unfrozen areas. In addition, the food richness of unfrozen areas declines due to greater use. For fish feeding birds we have assumed that increasing ice cover will not affect their numbers and this assumption is true. Ice cover is never 100% here; the shipping lane between Świnoujście and Szczecin is kept free of ice (Girjatowicz 1991; 2005) and there are also always other areas free of ice, especially at the mouths of small rivers flowing into the estuary. These areas free of ice may still abound in fish and provide food for fish feeders. When temperatures drop there is often an influx of new individuals arriving from the east and north. Comparison of estimates of a species' total European numbers (Wetland International 2016) with numbers for the Odra River Estuary is interesting since local trends and European trends do not always agree. Below we will discuss this for each species.

Scaup

Scaup wintering populations in northern and western Europe have been declining at an annual rate of -2.3%/year (Wetland International 2016). About 41% of the Scaup populations winters in Baltic Sea region (Skov et al. 2011) which has declined by 60% from 1991 to 2010 (Aunis 2013). Contrary to this we found Scaup numbers to have increased in the Odra River Estuary as has been mentioned by Skov et al. (2011) who describe a threefold increase in numbers in the Szczecin Lagoon and the eastern coastal areas of Germany and declines further west along the German coast, where areas like Wismar Bay and Traveförde support much lower numbers than 15 years ago. A similar trend exists in Sweden, where Nilsson and Haas (2016) show a significant increase in the number of wintering Scaup between 1971 and 2015. In the other hand at the most important wintering sites further west in the Netherlands, Hornman et al. (2012) showed decrease since 1980/1981. All of these studies confirm that Scaup are shifting their wintering range further north and east closer to their breeding areas and this is the reason for increased numbers of Scaup in the Odra River Estuary despite the decline in numbers of the species' European population.

Tufted Duck

Tufted Duck populations wintering in north-western Europe have been increasing at +0.3%/year (Wetland International 2016). In the Baltic Sea region there has been no changes in numbers between 1991 and 2010 (Aunis 2013). We also have found no significant changes in population size in our study area. Since this species requires patches of open water, we expected increasing numbers as was also seen for Scaup. Future observations may mimic changes found in Sweden where Nilsson and Haas (2016) showed populations to have increased between 1971 and 2015. Tufted Ducks in the Odra River Estuary behave similarly to Scaup in that they form mixed flocks that eat the same type of food (Marchowski et al. 2016). In a greater scale, however, Tufted Ducks have a different migration and wintering strategy; Scaup jumps between hot spots and concentrate their numbers at a few areas, while Tufted Ducks are have a more diffuse distribution (van Erden and de Leeuw 2010; Scov et al. 2011; Carboneras and Kirwan 2016a; Carboneras and Kirwan 2016b). Tufted Ducks will disperse to smaller water bodies outside of our study area while Scaup almost exclusively remain in the Odra River Estuary (e.g., Marchowski and Ławicki 2011; Marchowski et al. 2013).

Pochard

Pochard populations wintering in northern Europe have declined at an annual rate of -2.2%/year (Wetland International 2016). Pochard numbers in the Baltic Sea region have declined 70% between 1991 and 2010 (Aunis 2013). In 1995 this species' numbers from north-east/north-west Europe population was estimated at 300,000 individuals (Delany et al. 1999) and with a constant -2.2%/year decline, total population size now would now be about 190,000 individuals. Our study found significant reduction in the Odra River Estuary counts of the Pochard (Table 3) reflecting this species' global decline (Aunis 2013; Wetland International 2016). Numbers of Pochard had been expected to be greater in the Odra River Estuary because of the decrease in ice cover, but this species behaves more like the Tufted Duck than Scaup over winter in being more dispersed and occurring on smaller bodies of water (e.g. Marchowski and Ławicki 2011; Marchowski et al. 2013) meaning that individuals may be overwintering also outside the study area. The local decline, however, seems to be driven by the species' global decline despite the emergence of better conditions for wintering that might favor population growth.

Common Goldeneye

Goldeneye populations wintering in northern, western and central Europe has been increasing at +1.5%/year (Wetland International 2016) and have increased in the Baltic Sea region by 50% between 1991 and 2010 (Aunis 2013). BirdLife Inernational (2004) has estimated Goldeneye numbers to be about 1,430,000 individuals. In our work we found the Odra River Estuary to be of decreased importance for Goldeneye (Table 3), a trend opposite to this species' global situation (Aunis 2013; Wetland International 2016). Such situation can be explained by looking at this species' range and its behavior. The Goldeneye is short to medium distance migratory species (Carboneras et al. 2016). With global warming Goldeneye populations can remain nearer their to the main breeding distribution which is north and east from our study area. This behavior has been observed, e.g., Goldeneye numbers at Swedish wintering sites north of our study have increased (Nilsson and Haas 2016) and numbers at wintering sites in the Netherlands to the southwest have declined (Hornman et al. 2012).

Coot

Coot populations wintering in northern and western Europe have been more or less stable, annual change has been calculated as -0.1%/year (Wetland International 2016), but for the Baltic Sea region there has been a 60% decline between 1991 and 2010 (Aunis 2013).

Population estimates (Delany et al. 1999) suggest coot numbers to be about 1,715,000 individuals. We found no changes in coot numbers at the Odra River Estuary over the last 25 years (Table 3). Wintering sites located in warmer areas to the southwest in the Netherlands showed no changes in the number between 1975 and 2010 (Hornman et al. 2012), but for wintering sites to the north in Sweden numbers have generally increased from 1971 to 2015 except for a decline from 2004 to 2015 (Nilsson and Haas 2016). The expected increase in numbers due to the improvement in habitat quality was not observed. Factors such as pressure from American mink *Neovison vison*, which are responsible for the decline of Coot in many places (e.g., Ferreras and Macdonald 1999), may have held back potential increases.

Smew

Smew populations wintering in northern, western and central Europe have increased at +2.8%/year (Wetland International 2016) and for the Baltic Sea region numbers have increased 30% between 1991 and 2010 (Aunis 2013). Delany et al. (1999) estimated the Smew population wintering in north-west and central Europe to be about 69,650 individuals. We found a decrease in importance at the Odra River Estuary for Smew (Table 3). As with the Goldeneye this observation can be explained by a shift further north and east in wintering area boundaries due to climate warming (Pavon-Jordan et al. 2015; Nilsson and Haas 2016).

Goosander

Goosander populations wintering in northern, western and central Europe have shown a slight decline, measured at -0.3%/year (Wetland International 2016); there were no significant change in numbers for the Baltic Sea between 1991 and 2010 (Aunis 2013). Delany et al. (1999) estimated the total Goosander population size to be about 250,500 individuals. We found a decrease in the importance of Goosanders at the Odra River Estuary (Table 3). As with Goldeneye and Smew this observation can be explained by a shift further north and east in the wintering area boundaries due to climate warming (Hornman et al. 2012; Nilsson and Haas 2016).

Conclusion

There is no doubt that climate is changing, global temperature has risen about 1°C over the last 130 years, and Northern Hemisphere temperatures of the last 30 years have been the highest in over 800 years (Stocker et al. 2013). The extent and duration of ice coverage in the Baltic has decreased on average by 50% over the last 36 year (Schröder 2015). There is evidence that the range and occurrence of migratory birds has changed in response to climate change and that some species have shortened their migratory movements by wintering closer to their breeding areas (Musil at al. 2011; Pavon-Jordan et al. 2015; Meller 2016). Assuming continued climate warming, the negative correlation of numbers of benthic feeding birds with the number of days with ice cover indicates that the Odra River Estuary becomes more important for this group of birds. These changes locally to the Odra River Estuary are impacted by a number of factors, most notably to climate change and changes in a species' total numbers. This second factor is probably responsible for the local decline of the Pochard. Climate change seems to be the primary reason for increases in the number of Scaup and decreases in the numbers of Goldeneye, Smew and Goosander.

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Table 1. Size of biogeographic population and annual trend in change for seven species of waterbirds using the Odra River Estuary.

Species	Base number of individuals	Base year	Population trend % p.a.
Greater Scaup	310,000	1991	-2.3
Tufted Duck	1,750,000	1995	+0.3
Common Pochard	300,000	1995	-2.2
Common Goldeneye	1,000,000	1990	+1.5
Eurasian Coot	1,750,000	1995	-0.1
Smew	40,000	1995	+2.8
Goosander	266,000	1995	-0.3

Table 2. Results of generalized linear mixed models for seven species showing the influence of ice cover and season on percentage of occurrence of benthivores (denoted as B, Scaup, Tufted Duck, Pochard, Goldeneye, Coot) and piscivores (denoted as P, Smew, Goosander) species on the Odra River Estuary in relation to their biogeographicpopulation.

Greater Scaup [B]	Estimate	Std. Error	df	t value	*P*
Intercept	-1008.828	403.639	43		
Ice cover	-0.689	0.221	43	-3.114	**0.003**
Season	0.523	0.201	43	2.601	**0.013**
Tufted Duck [B]					
Intercept	24.651	29.610	43	0.833	0.410
Ice cover	-0.104	0.016	43	-6.387	**<0.001**
Season	-0.012	0.015	43	-0.780	0.439
Common Pochard [B]					
Intercept	70.341	21.838	43		
Ice cover	-0.048	0.012	43	-3.985	**<0.001**
Season	-0.035	0.011	43	-3.192	**0.003**
Common Goldeneye [B]					
Intercept	32.068	8.885	41.30		
Ice cover	-0.021	0.005	29.32	-4.07	**<0.001**
Season	-0.016	0.004	41.31	-3.576	**0.001**
Eurasian Coot [B]					
Intercept	0.390	10.910	41.24		
Ice cover	-0.030	0.007	37.32	-4.617	**<0.001**
Season	<0.001	0.005	41.24	0.003	0.997
Smew [P]					
Intercept	803.944	202.418	43		
Ice cover	0.031	0.111	43	0.279	0.781
Season	-0.399	0.101	43	-3.958	**<0.001**
Goosander [P]					
Intercept	320.887	137.849	40.24		
Ice cover	0.085	0.087	42.93	0.979	0.333
Season	-0.158	0.069	40.24	-2.308	**0.026**

Table 3. Changes in significance of Odra Estuary River (ORE) for biogeographical population (b.p) of diving waterbirds showing percent of biogeographical population in 1991; percent of biogeographical population in 2015; mean percent of biogeographical population in years 1991 – 2015 ± standard error; and trend in changes of significance the area for the species in years 1991 – 2015.

Species	%b.p.1991	%b.p.2015	Mean1991–2015±SE	Trend in ORE
Greater Scaup	6.58	12.18	8.70±3.12	↑
Tufted Duck	1.97	4.74	1.25±0.69	→
Common Pochard	1.64	0.51	0.51±0.72	↓
Common Goldeneye	1.18	0.32	0.25±0.43	↓
Eurasian Coot	0.49	0.51	0.35±0.44	→
Smew	2.60	1.91	3.09±2.58	↓
Goosander	6.07	1.82	3.32±1.84	↓

Figure 1. The Odra River Estuary, northwestern Poland.

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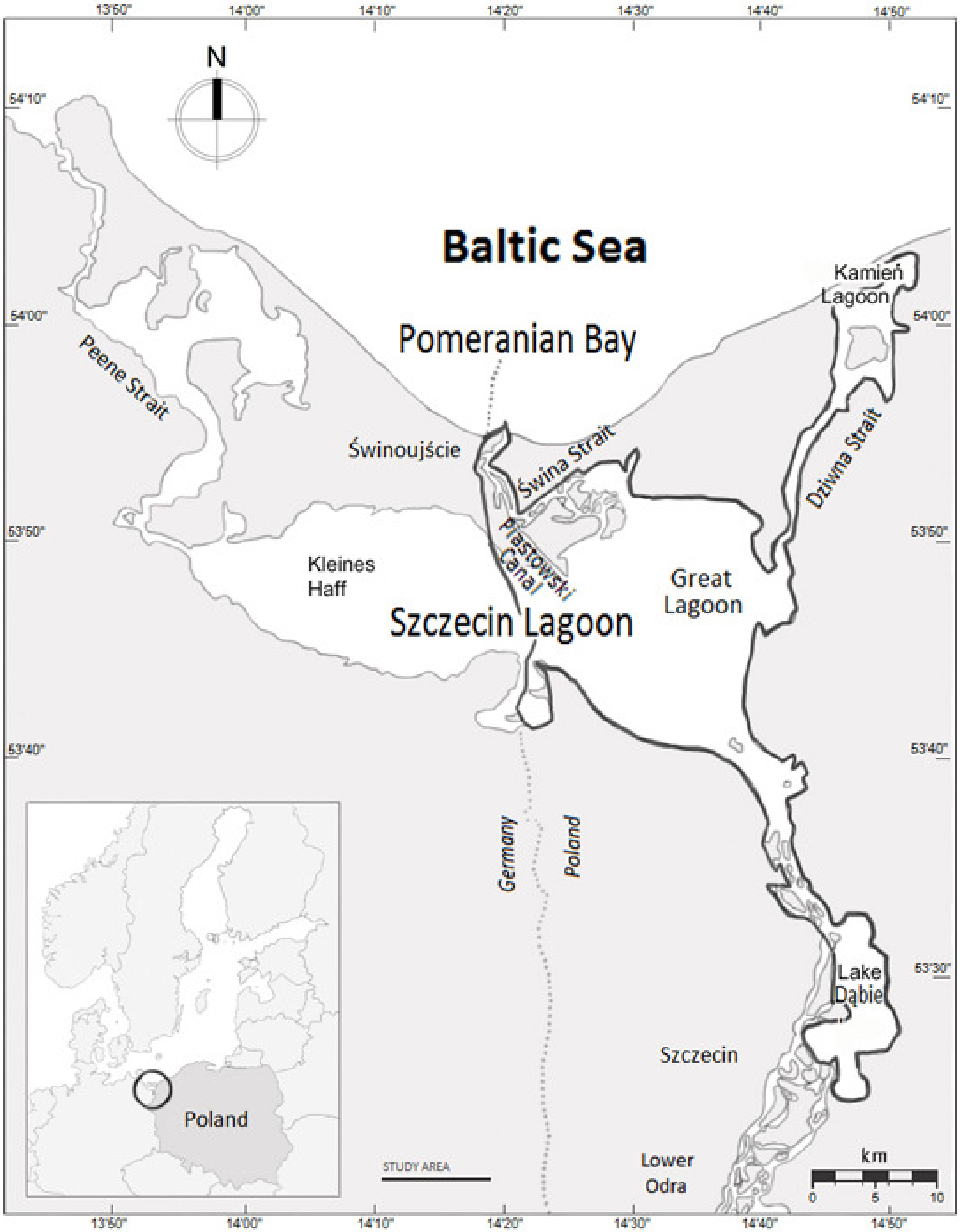
Baltic Sea
Pomeranian Bay
Peene Strait
Świnoujście
Świna Strait
Piastowski Canal
Kamień Lagoon
Dziwna Strait
Kleines Haff
Szczecin Lagoon
Great Lagoon
Germany
Poland
Lake Dąbie
Szczecin
Lower Odra
Poland
STUDY AREA
km
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