Journal of Sea Research 62 (2009) 268–275

Contents lists available at ScienceDirect

Journal of Sea Research

journal homepage: www.elsevier.com/locate/seares

Diet of red-throated divers *Gavia stellata* reflects the seasonal availability of Atlantic herring *Clupea harengus* in the southwestern Baltic Sea

Nils Guse [a,*], Stefan Garthe [a], Bernd Schirmeister [b]

[a] *Research and Technology Centre Westcoast (FTZ), University of Kiel, Hafentoern 1, D-25761 Buesum, Germany*
[b] *Seestraße 37a, 17429 Seebad Bansin, Germany*

ARTICLE INFO

Article history:
Received 11 December 2008
Received in revised form 27 May 2009
Accepted 22 June 2009
Available online 3 July 2009

Keywords:
Baltic Sea
Red-throated Diver
Atlantic Herring
Foraging Ecology
Seasonal Migration

ABSTRACT

Red-throated divers are piscivorous seabirds considered to be opportunistic feeders. The overall knowledge about their diet at sea is scarce. A large sample size of 82 by-caught red-throated divers from two winter (2001–02 and 2002–03) and three spring periods (2003, 2004 and 2005) offered the unique opportunity to analyse their dietary composition in the Pomeranian Bight. This area represents a hot spot in their winter distribution in the southwestern Baltic Sea and a marine protected area has been established due to its importance for the divers and other seabird species. Diet composition was analysed based on stomach and gut contents. The comparison of the different prey species was mainly based on reconstructed biomass using regressions between skeletal hard parts such as otoliths and original fish length and weight. The diet of the divers comprised eleven different fish species and nine different families. No interannual differences in the consumption of the nine most important prey species could be observed. However, in contrast to the other fish species the consumption of Atlantic herring and zander differed significantly between seasons. Herring supplied the majority of prey biomass in all three spring periods and zander in both winter periods. Moreover, the average length of herring consumed differed significantly between seasons. In winter, smaller herring was consumed compared to spring. The distinct seasonal changes in the diet composition were paralleled and most probably evoked by the migration pattern of the Western Baltic spring spawning herring which has its main spawning grounds adjacent to the study area. Based on the habitat requirements of the different prey species it could be inferred that mostly the coastal waters of the bight were used for foraging. Its function as spawning, nursery area and feeding ground with numerous resident and migrating fish species available might explain the important role of the Pomeranian Bight as wintering and staging area for red-throated divers in the southwestern Baltic Sea.

1. Introduction

Seabirds are apex predators in marine ecosystems, that feed on a variety of fishes, crustaceans and molluscs (Montevecchi, 1993). Even though seabirds have been shown to consume large amounts of fish (Furness, 1990), the overall fish consumption by larger predatory fish usually exceeds these amounts by magnitudes (Bundy et al., 2000). The group of piscivorous seabirds includes specialists, such as sandwich terns (*Sterna sandvicensis*) which are restricted to certain fish species and size of prey, at least in the breeding season (Stienen et al., 2000; McGinnis and Emslie, 2001), and generalists such as cormorants (e.g. Suter, 1997; Grémillet et al., 1998) and gulls (e.g. Spaans, 1971; Kubetzki and Garthe, 2003) which use a wide range of fish species and sizes. Most seabird species are probably opportunistic feeders to some extent, taking a rather broad range of fish species. One such species appears to be the red-throated diver (*Gavia stellata*) (see Madsen, 1957; Reimchen and Douglas, 1984; Anonymous, 2004). Hence, its diet composition seems to depend on availability rather than on food specialisation. The red-throated diver is rather elusive and of high conservation concern and in its wintering range restricted to nearshore, rather shallow marine waters. In the Baltic Sea, comprising one of their two main wintering areas (Durinck et al., 1994b), knowledge of the diet of piscivorous seabirds in general and red-throated divers in particular is scarce apart from information from very few localities (see Madsen, 1957; Zydelis, 2002). The Pomeranian Bight represents one of the most important staging and wintering areas for red-throated divers in the entire Baltic Sea and the most important site in the German part (Garthe et al., 2003). Their occurrence contributed to the designation of a Special Protection Area (SPA), a marine protected area according to the EU Wild Birds Directive (Garthe, 2006). We studied their diet here, during different seasons based on a substantial number of birds which were by-caught in set net fisheries. As the birds were apparently healthy and actively foraging when caught in the nets we assumed that the contents of

* Corresponding author. Tel.: +49 4834 604119; fax: +49 4834 604199.
E-mail address: guse@ftz-west.uni-kiel.de (N. Guse).

1385-1101/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.seares.2009.06.006

their digestive tract reflected their natural diet. Our study aimed at analysing the diet composition of red-throated divers to reveal the key prey species and to investigate the influence of spatio-temporal patterns in prey availability on the diet composition to demonstrate how seabirds might exploit their food base, especially under changing but predictable conditions. We hypothesized that seasonal changes in the availability of their main prey will be reflected in their diet generating seasonal patterns. Furthermore, as the spatial distribution of prey influences the distribution of predators, we tried to identify foraging habitats of red-throated divers in the Pomeranian Bight based on habitat preferences and distribution of fish species found in the birds' diet. Such approaches have been very useful to identify foraging habitats of study species (e.g. Zeppelin and Ream, 2006; Schwemmer and Garthe, 2008). The knowledge of these habitat relationships is of high importance when assessing the conservation relevance of different habitats.

2. Material and methods

2.1. Study site and origin of samples

The Pomeranian Bight is situated in the southwestern Baltic Sea (Fig. 1). The bight is rather shallow between 0 and 20 m deep and contains mostly brackish water with a salinity of 7.5 (Lass et al., 2001). Due to a large freshwater discharge containing substantial nutrient load of the rivers Odra and Peene (Mikulski, 1966) its hydrographic and biological properties are highly variable due to the interaction between seawater and freshwater (Chojnacki, 1999). As a consequence, the bight hosts a variety of different fish species that occur in fresh, brackish and marine water (see Thiel et al., 2007). Atlantic herring (*Clupea harengus*) is one of the most important fish in terms of biomass, and there are important spawning sites both in and adjacent to the bight (Klinkhardt, 1996; Gröhsler, 2003; www.clupea.net/stocks/index.html).

All samples analysed originated from red-throated divers that had drowned in set nets in the Pomeranian Bight. We assumed that the divers were not taking fish from the nets since the fish caught in the large mesh nets were most likely too large for the divers to swallow. During winter, an extensive set net fishery takes place off eastern Rügen, mainly by German part-time fishermen (see Fig. 2a). The nets seemingly follow the 10 m depth line along the coast of Usedom (Mecklenburg-Vorpommern, Germany) where thus all studied birds should have been caught. During spring, the set net fishery is more intensive but the highest set net densities occur in the same areas (see Fig. 2b). Nets are between 30 and 70 m long and are set above the sea floor. These single nets are linked to a chain of nets which usually comprises 10 to 20 nets reaching 300 to 700 m in length (T. Richter, Landesamt für Landwirtschaft, Lebensmittelsicherheit und Fischerei Mecklenburg-Vorpommern (LALLF M-V), pers. comm). The nets are checked between two and four times a week. The divers used in this study stemmed from set nets which were used to catch zander (*Sander lucioperca*) or cod (*Gadus morhua*). In total, we analysed a subsample of 82 birds from two winter and three spring periods (Table 1). For these five periods a total of 11 adult, 3 subadult and 91 immature female birds as well as 12 adult, 3 subadult and 80 immature male birds was available. In order to analyse a homogenous and balanced sample all analysed birds were immatures and each period contained an equal sample size of male and female birds.

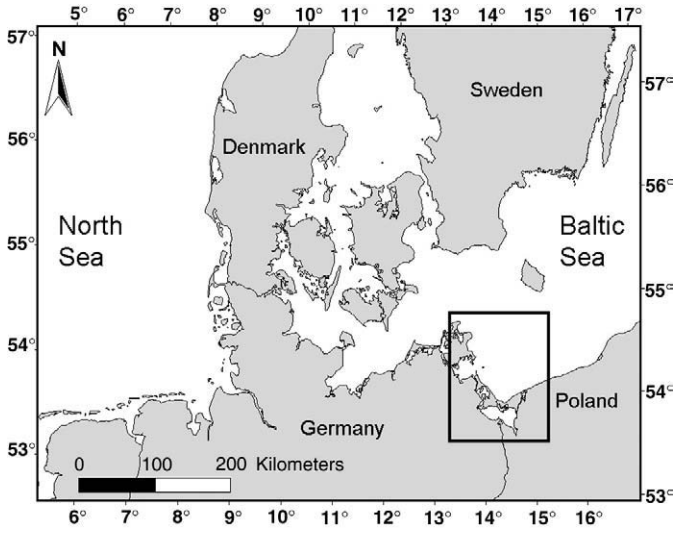

Fig. 1. Study site: the Pomeranian Bight in the southwestern Baltic Sea.

2.2. Dissection and diet analysis

The body condition was derived via a condition index based on the status of pectoral flight muscles and fat depots (van Franeker, 2004; van Franeker and Camphuysen, 2007). From all red-throated divers analysed, 72 birds were in good and 10 in a moderate body condition. Additionally, the birds were sexed and aged according to the development of their sexual organs and the status of the Bursa Fabricius (Camphuysen and van Franeker, 2007). The latter was present in 76, absent in 4 and could not be judged in 2 of the analysed 82 birds. Finally, stomach and gut were removed for diet analysis and were treated for each bird as one unit. The stomach and gut were sliced open over their full lengths and whole fish and larger fragments were taken out of the stomach. The remaining contents were carefully rinsed into a container and flushed out with tap water separating the identifiable remains from amorphous material (see Ouwehand et al., 2004). Gut samples were treated accordingly. Whole fish and larger fish fragments were identified according to Muus and Nielsen (1999). For the identification of digested fish different hard parts of the skeleton were used and analysed to the lowest possible taxon (see Ouwehand et al., 2004). Sagittal otoliths were identified according to Härkönen (1986) and Leopold et al. (2001), premaxillae, vertebrae to Watt et al. (1997), otic bullae to Blaxter and Hunter (1982), Watt et al. (1997), Ouwehand et al. (2004), scales to Maitland (1972), (März, 1972) and dorsal and pelvic spines of sticklebacks to Leopold et al. (2001). Additionally, our own reference collection was used. If fish remains could not be identified to species level these specimens were grouped accordingly (e.g. Clupeidae indet.; fish indet.). The number of fishes consumed was directly counted or estimated from the remains. Otoliths, pelvic spines and otic bullae were assigned as left, right (Fig. 3) or unknown and were subsequently paired based on species, orientation, size, wear, colour and shape of the otoliths. Single left and right otoliths as well as pairs were each counted as one fish (Marteijn and Dirksen, 1991). In sticklebacks, where otoliths are easily missed, dorsal and pelvic spines provided a more accurate estimation of the number of sticklebacks consumed (Leopold et al., 2001; M.F. Leopold unpubl. data). The number of specimens of a given species that is based on identified otoliths was compared to the number that is derived from other remains taking the minimum number of fish of that particular species into account, thus avoiding potential double counts. For calculating the original fish length and mass, usually the total length and width of each otolith was measured except for broken ones, for which in the majority of cases only the width could be determined. The equations used for unworn otoliths usually have a bias in the order of +/− 5 to 10% (Härkönen, 1986). As hard parts are worn down during the digestion process (Leopold et al., 2001; Christiansen et al., 2005) calculated fish sizes based on worn hard parts (otoliths and spines) would lead to a systematic underestimation of original fish