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First data on the diet of Razorbill *Alca torda* wintering in the Mediterranean Sea: insights from social media

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Abstract

Understanding a species' diet is of paramount importance to ecology as it provides vital insights into interactions between organisms and their environment. In this study, we report the first data on the diet of wintering Razorbills (*Alca torda*) in the Mediterranean Sea. Taking advantage of the irruption event that occurred in the Mediterranean in winter 2022/2023, a data mining search campaign was carried out on social media to collect photographs and videos documenting Razorbills feeding at sea. Additional information was gathered by analysing the stomach contents of dead individuals salvaged from the coastline of central Italy. Overall, we obtained records from 32 pictures and 7 videos as well as 7 dead individuals. All prey items belonged to class Actinopterygii. Overall, 12 fish prey were identified (2 at the family, 3 at the genus and 7 at the species level). Razorbills fed on small-medium sized fish species of the neritic zone such as *Belone belone*, *Trachinotus ovatus*, *Atherina hepsetus* and *Engraulis encrasicolus*. Razorbills were mostly observed foraging close to the coast and within harbours, as well as begging for food from humans, raising doubts about the feeding conditions encountered and the health status of individuals. Dead individuals mainly had empty stomachs, in line with the low weights and fat scores detected during necropsy. We underline how data from social media have made it possible to describe, using non-destructive methods, the behaviour and feeding habits of an uncommon seabird typical of the North Atlantic Sea, which caught the attention of photographers, nature enthusiasts, and scientists.

Keywords: Alcidae; citizen science; feeding ecology; digital photography; marine birds; fish; public engagement.

Introduction

Seabirds represent an integral part of marine ecosystems and can be used as excellent indicators of environmental state and related changes (Furness & Camphuysen, 1997; Piatt *et al*., 2007; Thibault *et al*., 2019). Ecological studies on seabirds can assist researchers in the early detection of changing oceanographic conditions and fish stock fluctuations (Frederiksen *et al*., 2004; Furness, 2007). They can also provide insights in food web structure and dynamics and inform on the impact of human activities on environmental processes (e.g., fishing activities; see Grémillet & Charmantier, 2010). In this context, valuable contributions can be made by studies that focus on feeding habits and dietary shifts of target species (Bearhop *et al*., 2001). Such studies can reveal environmental changes at sea that are typically associated with specific movement patterns and/or population dynamics (e.g., Gaard *et al*., 2002). Diet studies have historically been conducted using a variety of methods, such as field observation at seabird colonies, stomach content inspection, pellet and regurgitated food analysis, investigation of faeces components and stable isotopes analyses (e.g., Barrett *et al*., 2007). For example, Glew *et al*. (2019) showed how the shift in the dietary trophic level of the Razorbill *Alca torda* (Linnaeus, 1758) was associated with displacement to more distant southerly waters in the North Sea because of poor overwinter survival. Similarly, Bearhop *et al.* (2001) showed how annual variation in the diet of the Great Skua *Catharacta skua* was associated with the presence of fishing vessels, as revealed by integrating conventional dietary assessment with stable isotope techniques. Unpredictable changes in environmental conditions can also reshuffle resource availability and accessibility at sea, often leading to unusual movement patterns in seabirds, such as occasional irruption events (e.g., Ryan *et al*., 1989; Newton, 2010). Such occasional displacement of large numbers of individuals from their normal range may lead individuals to switch diets to adapt to the new conditions (Jones *et al*., 2018).

The Razorbill is a large-sized auk with breeding areas located in boreal and sub-Arctic waters of the North Atlantic. This species usually inhabits shallow waters in coastal areas. At the end of the breeding season, it moves towards open waters in the North Atlantic where it usually spends the winter (Lavers *et al*., 2007a). Displacements occurring at more southern latitudes are also documented, with individuals redistributing across the Atlantic coasts of France and Portugal (e.g., Teixeira, 1986; Pasquet, 1988), extending as far south as the Canary Islands and entering the western Mediterranean in small numbers (Carboneras, 1988). Occasionally, irruption events can occur, with unusually large numbers of individuals entering the Mediterranean Sea and dispersing in countries such as Spain and France, but also Italy, Algeria, Tunisia, Libya, Malta and Greece, as recently documented by several authors (De La Cruz *et al*., 2022; Balestrieri *et al*., 2023; Boutabia *et al*., 2023; Ouni *et al*., 2023). At a global level, the population size is estimated to be around 700,000 pairs, with most (80%) concentrated in Iceland and the British Isles (Harrison *et al.*, 2021). However, while generally considered a common species, little is known about it compared to other auks (Gaston & Jones, 1998), although some of its ecological and biological aspects have recently been investigated (Insley *et al*., 2003; Lavers *et al.*, 2007b; Balestrieri *et al.*, 2023 and references therein).

In summer, this bird preys especially on small-sized Atlantic fish species, mostly comprising clupeids (Clupeidae), sandeels (Ammodytidae) and gadoids (Gadoidei) (Ouwehand *et al*., 2004; St John Glew *et al*., 2019). In winter, data on feeding habits of Razorbills are limited (Freethy, 1987; Espín *et al*., 2012). It has been suggested that clupeids, being "fatty fishes", represent an important energy source for Razorbills, especially during winter months (Barrett, 2015). A series of studies demonstrated that species such as the Capelin *Mallotus villosus*, the Atlantic Herring *Clupea harengus* and sandeels (*Ammodytes* spp.) may represent an important food source for Razorbills (Lavers *et al*., 2007b; Barrett, 2015). In a study examining dead Razorbills wintering off the Portuguese coast, pilchards, anchovies and sandeels were recorded as prey (Beja, 1989). Invertebrates, such as small crustaceans and polychaetes, detected through stomach content analysis, can also occupy a relevant place in the diet of the species (Huettmann *et al*., 2005; Moody & Hobson 2007). From other studies, it also appears that these auks can occasionally feed on zooplankton (e.g., krill; Tuck, 1961; Huettmann *et al*., 2005), although it is uncertain whether this food source is significant or regular.

Even though Razorbills are regularly observed in Italy and in the Mediterranean Sea in winter, this is generally limited to only a few individuals per year, with the exception of recently reported extraordinary irruption events during which hundreds of individuals congregated at sea (e.g., the most recent one being in winter 2022/2023; Balestrieri *et al*., 2023). To the best of our knowledge, data on the diet of the Razorbills that spend the winter in the Mediterranean Sea (an oligotrophic sea) are absent. It has been postulated that some fish species included in their diet during the breeding season in the Atlantic, such as sardines (e.g., the European Pilchard *Sardina pilchardus*), are common year-round even in the Mediterranean Sea and can therefore represent an exploitable resource for wintering individuals (Espín *et al*., 2012). Studying seabirds' diet in winter is often complicated by the fact that the individuals stay offshore, thus being difficult to observe. In the case of the 2022/2023 irruption event, many individuals remained close to shore for months at a time and allowed birdwatchers, photographers and other citizen scientists to take photographs and collect data on feeding habits and prey (Balestrieri *et al*., 2023; Boutabia *et al*., 2023). Non-invasive methods for data collection such as digital photography and/or citizen science data have been already used as an accurate and efficient method for dietary studies in seabirds (e.g., Ward *et al*., 2015; Forys & Hevesh, 2017; Gaglio *et al*., 2017; Viola *et al*., 2022).

In this paper, we report the first data on the diet of Razorbills wintering in the Mediterranean Sea. We used an integrated approach combining direct methods (e.g., stomach content analysis of stranded individuals) with data mining on social media and citizen-science websites to collect photographic documentation of prey items. We detail the main prey items, describe peculiar foraging behaviours, and discuss potential drawbacks for the individuals wintering in the Mediterranean Sea. We further highlight the potential of citizen science data and photographs as non-destructive and non-invasive methods to gather information on the diet of seabirds.

Materials and Methods

Data collection

Between November and December 2022, we searched for photos and videos showing the feeding behaviour of wintering Razorbills in the Mediterranean basin published on the main social media applications (i.e., Facebook, Instagram, X and TikTok), online citizen science platforms (i.e., iNaturalist, Ornitho, EBird) and video- and photo-sharing websites (i.e., Juzaphoto, Flickr, Pinterest and YouTube). Search terms included all possible combinations of these words: "Razorbill", "*Alca torda*", "diet", "feeding" and "Mediterranean". Despite finding a large number of photos/videos of Razorbills on social media during the study period (n = 238; these records were used to describe the irruption event; Balestrieri *et al*., 2023), only a few images portrayed individuals feeding on prey. For this study, we analysed only photos and videos where Razorbills were shown with their prey. We discarded seven records (5 pictures and 2 videos) for which image quality was too low to identify prey items at any taxonomic level. All available videos were stored in a dataset including date of the photo/video, location (coordinates in WGS84 system), origin of the video (i.e., social media, websites or citizen-science platforms), authors, and identification (whenever possible) to the lowest possible taxonomic level of the prey species. Indeed, in many cases, species-level identification was not achievable due to the low quality or the angle of the photos/videos, which hindered the observation of specific diagnostic characteristics necessary for species identification. Our research was conducted in ten languages (English, French, Italian, Greek, Arab, Spanish, Albanian, Croatian, Slovenian and Maltese). We also forwarded a request to the owners of the images/videos posted on social media for extra material not published online. This helped us obtain a few more photos and videos. In case of multiple pictures for the same bird with the same prey (verified with the authors of the photo by checking location and timestamp) only one image was selected for identification. All data collected underwent scientific validation and experts accurately identified prey items. In the case of videos showing one or more individuals actively hunting, we attempted to identify the chased prey. We excluded data from photos or videos depicting individuals begging for and receiving food from humans so as not to alter our analysis. However, we do discuss begging for food in our analysis of peculiar behaviours.

Furthermore, we analysed carcasses and stomach contents of six individuals found stranded and/or rescued along the Italian coast during the same period (winter 2022/2023). Stranded individuals were brought to different laboratories or museums for relevant analyses. The following biometric measurements were taken: a) body mass was measured with a 2500 g Pesola scale. Using a digital calliper (± 0.01 mm) we also measured (Fig. S1): b) head length (HL) measured as the distance between the tip of the bill and the back of the head; c) beak length (BL) as the distance between the tip of the bill and feathers (e.g., based on Camphuysen *et al*., 2007; Singh *et al.*, 2015); d) bill depth (BD) as the distance between the top and bottom of the bill, measured at the gonys (e.g., Camphuysen *et al*., 2007). We also recorded subcutaneous and abdominal fat scores and the level of breast muscle in accordance with the EURING Code Manual (Du Feu *et al.*, 2016; https://euring.org/data-and-codes/euring-codes). If present, prey items were extracted and identified to the species (when possible) or higher levels. All descriptive data are reported as mean ± standard deviation.

Results

Photographs and videos from social media

Overall, we obtained 39 records (32 pictures and 7 videos) of Razorbills feeding at sea during the irruption event of 2022/2023 (Table 1 and Table S1). Records came from four Mediterranean countries (Spain, France, Italy and Greece). In four cases, the prey item was classified as "fish waste", when it concerned fish remains discarded from vessels at ports. For the remaining cases, it was possible to identify prey items for 54.3% of the records (19 out of 35), albeit not always at the lowest level levels (Table 1). Prey targeted by Razorbills were mainly pelagic fish of the neritic zone (Fig. 1). In all other cases (n = 16), the identification at species level was not possible, though all prey items belonged to class Actinopterygii (Table 1; Table S1).

Stomach content of dead Razorbills

Overall, we analysed the stomach contents of 6 individuals (all juveniles) salvaged from the coasts of central and southern Italy (4 from Campania and 2 from Tuscany). Another individual found in Campania in poor conditions but still alive was brought to a rehabilitation centre and fed for *ca.* one month before dying. It was not included in the analysis, though body measurements upon entry to the rescue centre were recorded (Table 2). The mean weight of salvaged individuals was 539.8 ± 146 g (n = 7), while fat scores ranged between 0 and 4. Four individuals had empty stomachs. In two cases, stomach content analyses revealed the presence of fishes, identified as Mediterranean Sand Smelt *Atherina hepsetus* (n = 4 individuals) and Boxlip Mullet *Oedalechilus labeo* (n = 1 individual) in one case, and European Pilchard *Sardina pilchardus* (n = 2 individuals) in the other case (Tables 1-2; Fig. 1h). Further details of prey items in stomach content analyses as well as body condition of the salvaged Razorbills are summarized in Table 2.

Discussion

Cairns (1987) pioneered an integrated approach to utilizing seabirds as indicators of marine food availability, and in a subsequent work (Cairns, 1992) he emphasized the imperative for enhanced collaboration between seabird biology and fisheries science to mutually advance the conservation of avian species and fish populations. In light of escalating apprehensions regarding the preservation of marine ecosystems, which support extensive fishing activities (Zhao & Li, 2022), the urgency of monitoring seabird diets and integrating seabird populations

Table 1. List of prey items (at different taxonomic levels) in the diet of Razorbills wintering in the Mediterranean Sea during the irruption event of 2022/2023. Number of records and file types are specified.

Class	Order	Family	Genus	Species	N records	File types
Actinopterygii	na	na	na	na	16	picture and video
Actinopterygii	Clupeiformes	na	na	na	2	video
Actinopterygii	Perciformes	Sparidae	na	na	1	picture
Actinopterygii	Perciformes	Gobiidae	na	na	1	picture
Actinopterygii	Atheriniformes	Atherinidae	Atherina	na	1	picture
Actinopterygii	Perciformes	Centracanthidae	Spicara	na	2	picture
Actinopterygii	Perciformes	Carangidae	Trachurus	na	3	picture
Actinopterygii	Beloniformes	Belonidae	Belone	*Belone belone* (Linnaeus, 1760)	4	picture
Actinopterygii	Clupeiformes	Clupeidae	Sardinella	*Sardinella aurita* Valenciennes, 1847	1	picture
Actinopterygii	Clupeiformes	Engraulidae	Engraulis	*Engraulis encrasicolus* (Linnaeus, 1758)	2	picture
Actinopterygii	Perciformes	Carangidae	Trachinotus	*Trachinotus ovatus* (Linnaeus, 1758)	2	picture
Actinopterygii	na	na	na	fish waste	4	picture
Actinopterygii	Atheriniformes	Atherinidae	Atherina	*Atherina hepsetus* Linnaeus, 1758	1	stomach content
Actinopterygii	Mugiliformes	Mugilidae	Oedalechilus	*Oedalechilus labeo* (Cuvier, 1829)	1	stomach content
Actinopterygii	Clupeiformes	Clupeidae	Sardina	*Sardina pilchardus* (Walbaum, 1792)	1	stomach content

Table 2. Physical conditions and stomach contents of Razorbills salvaged in Italy during the irruption event in winter 2022/2023. For each individual we reported the locality, date of recovery, status, age class and biometric measurements: body mass upon arrival at the center (BM); head length (HL) measured as the distance between the tip of the bill and the back of the head; beak length (BL) as the distance between the tip of the bill and feathers; bill depth (BD) as the distance between the top and bottom of the bill, measured at the gonys; as well as scores of the subcutaneous and abdominal fat and level of breast muscle in accordance with the EURING Code Manual (Du Feu *et al.*, 2016; https://euring.org/data-and-codes/euring-codes). Stomach content was also indicated and the species identified and reported. The symbol * indicates an individual rescued alive that stayed at the rehabilitation centre for more than one month (and that was fed by veterinarians) and died subsequently; analysis of its stomach contents was not performed.

ID	Region	Locality	Date of recovery	Status	Age class	BM (g)	HL (cm)	BL (cm)	BD (cm)	Subcutaneous fat	Abdominal fat	Breast muscle	Stomach content	N prey items	Prey identified
1	Tuscany	Porto Santo Stefano	30/11/2022	dead	juv	440	9.39	3.91	1.43	0	0	1	empty	0	na
2	Tuscany	Follonica	07/12/2022	dead	juv	480	9.4	3.93	1.54	1	1	1	empty	0	na
3	Campania	Bacoli	13/01/2023	dead	juv	800	9.37	3.91	1.44	4	2	3	content	5	4 *Atherina hepsetus*, 1 *Oedalechilus labeo*
4	Campania	Napoli Nisida	24/11/2022	dead	juv	690	9.5	3.94	1.55	3	2	3	content	2	2 *Sardina pilchardus*
5	Campania	Ischia	29/01/2023	dead	juv	409	9.45	3.93	1.45	1	0	1	empty	0	na
6	Campania	Procida	03/02/2023	dead	juv	480	9.37	3.94	1.47	1	0	1	empty	0	na
7	Campania	Vietri sul Mare	15/02/2023	alive*	juv	480	9.37	3.94	1.47	1	0	1	empty	na	na

Fig. 1: *Razorbill diet in the Mediterranean Sea.* Examples of Razorbill prey items as documented by photographs/videos resulted from data mining of social networks and stomach content analysis (cfr. Table 2). Pictures shown here are those whose authors have agreed to their use by signing the release agreement and whose names are reported with the description of the prey item of the related picture: a) *Sardinella aurita* - Strait of Messina (ME), 20/12/2022 - © Alessandro Micalizzi; b) *Trachinotus ovatus* - Pegli (GE), December 2022 - © Davide De Michele; c) *Belone belone* - Ceriale (SV), 07/12/2022 - © Monica Mugnosso; d) Fish waste - Porto S. Stefano (GR), 01/12/2022 - © Marco Brandi; e) *Engraulis encrasicolus* – Genova (GE), 04/01/2023 - © Savino Zorzetto; f) Sparidae – Anzio (RM), 05/12/2022 - © Fernando Ferri; g) and h) examples of fish remains in the stomach of two Razorbills (bird ID #3 and #4 as indicated in Table 2) found dead in Campania (cfr. Tab. 2) - © Carola Murano. In particular, four specimens of *Atherina hepsetus* and one of *Oedalechilus labeo* (the specimen at the bottom) in g) and remains of two specimens of *Sardina pilchardus* in h) are depicted.

into regional marine ecosystem models is growing increasingly apparent.

Exploiting the unique circumstances represented by the extraordinary irruption event of 2022/2023, we successfully collected first data on the diet of wintering Razorbills in the Mediterranean Sea. Notably, social media and nature photographs were confirmed to be important tools to assess the ecology of some poorly-studied species or those whose diet is hard to study (e.g., insectivore and pelagic bird species; see Forys & Hevesh, 2017), but also to discover new behaviour/associations and monitor biodiversity (Tiralongo *et al*., 2019; Azzurro & Tiralongo, 2020) and/or for the evaluation of avian invasions (e.g., Cohen *et al*., 2022).

Studies on the diet of Razorbills wintering in the Atlantic have shown the prevalence of fishes (e.g., Capelin, Atlantic Herring and Sandeels) (Beja, 1989; Lavers *et al*., 2007b; Barret, 2015), krill and other crustaceans and polychaetes (Huettmann *et al*., 2005; Moody & Hobson, 2007). To the best of our knowledge, no data had previously been available on the diet of Razorbills spending the winter in the Mediterranean Sea. Until now, the only information on the feeding habits of individuals entering the Mediterranean through Gibraltar was indirectly provided by the analysis of mercury levels in tissues of individuals that had drowned in fishing nets in southeastern Spain. In this study, Espín *et al*. (2012) found mercury concentrations higher than those in northern latitudes (e.g., Atlantic Ocean), probably due to differences in dietary habits during winter. However, since Razorbills are known to usually target prey with an average body length of 115 mm (Engvall *et al*., 2022) and generally smaller than 250 mm (Bradstreet & Brown, 1985), the authors suggested that some fish species of that size, such as *Sardina pilchardus*, present both in the Atlantic and in the Mediterranean, could constitute potential Razorbill prey in the Mediterranean as well. The Razorbill is a specialized but highly flexible top predator capable of adapting rapidly to climate change and able to track changes of preferred prey even well outside the boundary of their normal range (e.g., Gaston & Woo, 2008), and can shift dietary trophic levels under certain circumstances (e.g., Glew *et al*., 2019). Compared to the highly productive Atlantic Ocean, the Mediterranean Sea is characterized by relatively warm and oligotrophic waters with lower nutrient concentrations due to limited dynamics of significant upwellings (Tanhua *et al*., 2013). This could suggest that foraging opportunities for a seabird typical of cold, highly productive waters could be suboptimal in the Mediterranean Sea in terms of both prey quality and abundance. Observations of individuals getting close to the coasts/harbours and feeding on discarded fishery by-catch bolster this hypothesis. However, since we have only a few such observations (e.g., Fig. 1D), further investigation based on larger samples would be needed to better elucidate it.

The massive presence of Razorbills in the Mediterranean has been documented on social media with hundreds of photos and videos (Balestrieri *et al*., 2023), but few of these posts actually portrayed individuals with identifiable prey in their bills. Despite the small sample size and the non-standardized data collection from social media sources, our observations showed that Razorbills in the central Mediterranean Sea foraged on various species of fish with varying sizes. Targeted prey were Actinopterygii mostly belonging to species living in the neritic zone, with size spanning from about 50 mm to 200-300 mm (larger sizes for Sparidae specimens and *Belone belone*). Identified species were similar in size and habits to those commonly exploited in the North Atlantic Ocean by Razorbills (Lavers *et al*., 2007b; Barret, 2015). Indeed, some prey item (e.g., mackerels, pilchards and anchovies) were also found in the diet of Razorbills wintering off the Atlantic coats of Portugal and France, as described in previous literature (e.g., Teixeira, 1986, Pasquet, 1988; Beja, 1989). However, we also note that there may be a bias towards large prey items, while smaller items may be consumed underwater (e.g., Swennen & Duiven, 1977), and thus may not be detectable using images and videos. Most of the photographs and videos of Razorbills chasing prey and feeding at sea were made close to the coast or even within ports. This may reflect the fact that photographers and amateurs were concentrated along the coasts as opposed to at sea (Balestrieri *et al.*, 2023), but it may also be due to shallower waters and abundance of small fry that Razorbills could easily prey on, as discussed by Boutabia *et al.* (2023). At the same time, this can also mean that observed individuals were those most easily approachable by photographers, thus possibly representing the weakest individuals within the wintering population. In some cases, individuals were observed exploiting and consuming fish discarded from vessels at ports (Fig. 1D), thus suggesting that they opportunistically targeted easier food resources. The individuals with prey items in the stomach were those showing higher fat and breast muscle scores, while those found dead had lower scores and empty stomachs, suggesting they probably experienced a critical shortage in food supply. Interestingly, we also collected videos showing individuals begging for food at ports and accepting food directly from the hands of fishermen or curious bystanders. This peculiar behaviour, although anecdotal, may indicate that the observed individuals were in suboptimal physical condition, likely associated with the irruption event. This is not the only possible interpretation, as begging could be an energy-efficient foraging strategy. However, further studies using an integrated approach (e.g., including stable isotopes and/or pathogens analyses) would be needed to better elucidate the health status of these birds, their origin and causes of mortality, as well as to interpret such peculiar behaviours/strategies.

Overall, our study not only contributes to our understanding of Razorbills in the Mediterranean Sea, but also demonstrates the power of social media in advancing ecological research and raising awareness about unique events such as this irruption.

Conclusions

In conclusion, the Razorbills that irrupted into the Mediterranean Sea in 2022/2023 adapted to the local fish fauna by targeting species of similar shape and size as those that make up the core of their diet in their main wintering areas in the Atlantic. However, they also showed peculiar feeding behaviours such as foraging close to shorelines or even within ports, as documented by photos and videos made by citizens. Records of food begging directed to humans together with stomach content analysis and fat scores of retrieved birds suggest suboptimal health status and poor feeding conditions at sea. Citizen science data and their sharing on social platforms and networks contributed to the gathering of valuable information. More specifically, digital photography data allowed to accurately investigate the feeding habits of Razorbills and to identify their prey items at a time when an exceptionally high number of them found themselves in an oligotrophic sea. Appraising and monitoring peculiar movement patterns (e.g., irruption events) and how seabirds respond and adapt to new circumstances is key to understanding and reconstructing environmental changes at sea and crucial to predicting future biological responses.

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References

Azzurro, E., Tiralongo, F., 2020. First record of the mottled spinefoot *Siganus fuscescens* (Houttuyn, 1782) in Mediterranean waters: a Facebook based detection. *Mediterranean Marine Science*, 21, (2) 448-451.

Balestrieri, R., Vento, R., Viviano, A., Mori, E., Gili, C. *et al.,* 2023. Razorbills *Alca torda* in Italian seas: a massive irruption of historical relevance and role of social network monitoring. *Animals*, 13, 656.

Barrett, R.T., 2015. The diet, growth and survival of Razorbill *Alca torda* chicks in the southern Barents Sea. *Ornis Norvegica*, 38, 25-31.

Barrett, R.T., Camphuysen, C.J., Anker-Nilssen, T., Chardine, J.W., Furness, R.W. *et al.,* 2007. Diet studies of seabirds: a review and recommendations. *ICES Journal of Marine Science*, 64, 1675-1691.

Bearhop, S., Thompson, D.R., Phillips, R.A., Waldron, S., Hamer, K.C. *et al.,* 2001. Annual variation in great skua diets: the importance of commercial fisheries and predation on seabirds revealed by combining dietary analyses. *The Condor*, 103, 802-809.

Beja, P.R., 1989. A note on the diet of Razorbills *Alca torda* wintering off Portugal. *SEABIRD*, 12, 11.

Boutabia, L., Menaa, M., Mederbal, K.E., Boulaouad, B.A., Ayyach, K., *et al.,* 2023. Recent and exceptional irruption of the razorbill *Alca torda* (Linnaeus, 1758) on the Algerian coastline. *Natura Croatica*, 32, 233-239.

Bradstreet, M.S.W., Brown, R.G.B., 1985. Feeding ecology of the Atlantic Alcidae. p. 264-318. In: Nettleship, D.N., Birkhead, T.R. (Eds.), The Atlantic Alcidae: The Evolution, Distribution, and Biology of the Auks Inhabiting the Atlantic Ocean and Adjacent Water Areas. Academic Press, NY.

Cairns, D.K., 1987. Seabirds as indicators of marine food supplies. *Biological Oceanography*, 5, 261-271.

Cairns, D.K., 1992. Bridging the gap between ornithology and fisheries science: use of seabird data in stock assessment models. *The Condor*, 94, 811-824.

Carboneras, C., 1988. The auks in the western Mediterranean. *Ringing & Migration*, 9, 18-26.

Camphuysen, C.J., Bao, R., Nijkamp, H., Escuer, R.G., Heubeck, M., 2007. Handbook on oil impact assessment. Available at: http://www.zeevogelgroep.nl/CJC/

Cohen, T.M., Hauber, M.E., Akriotis, T., Crochet, P.A., Karris, G. *et al.*, 2022. Accelerated avian invasion into the Mediterranean region endangers biodiversity and mandates international collaboration. *Journal of Applied Ecology*, 59, 1440-1455.

De La Cruz, A., Rollán, L., Pérez, B., Guerrero, M., Elorriaga, J. *et al.,* 2022. Phenology and wintering population estimates of auks in the Mediterranean Sea based on counts from a strategic coastal location in the Strait of Gibraltar. *Ardeola*, 69, 303-317.

Du Feu, C.R., Clark, J.A., Schaub, M., Fiedler, W., Baillie, S.R., 2016. The EURING Data Bank–a critical tool for continental-scale studies of marked birds. *Ringing & Migration*, 31 (1), 1-18.

Engvall, E., Waldenström, J., Hentati-Sundberg, J., 2022. Diet and prey size preference in Razorbills *Alca torda* breeding at Stora Karlsö, Sweden. *Ornis Svecica*, 32, 87-98.

Espín, S., Martínez-López, E., Gómez-Ramírez, P., María-Mojica, P., García-Fernández, A.J., 2012. Razorbills (*Alca torda*) as bioindicators of mercury pollution in the southwestern Mediterranean. *Marine Pollution Bulletin*, 64 (11), 2461-2470.

Forys, E.A., Hevesh, A.R., 2017. Investigating Black Skimmer chick diets using citizen science and digital photography. *Southeastern Naturalist*, 16 (3), 317-325.

Freethy, R., 1987. Auks: an ornithologist's guide. Blandford Press.

Frederiksen, M., Wanless, S., Harris, M.P., Rothery, P., Wilson, N.J., 2004. The role of industrial fisheries and environmental change in the decline of North Sea black-legged kittiwakes. *Journal of Applied Ecology*, 41, 1129-1139.

Furness, R.W., 2007. Responses of seabirds to depletion of food fish stocks. *Journal of Ornithology*, 148 (Suppl 2), 247-252.

Furness, R.W., Camphuysen, C.J., 1997. Seabirds as monitor of the marine environment. *ICES Journal of Marine Science*, 54, 726-737.

Gaglio, D., Cook, T.R., Connan, M., Ryan, P.G., Sherley, R.B.,

2017. Dietary studies in birds: testing a non-invasive method using digital photography in seabirds. *Methods in Ecology and Evolution*, 8 (2), 214-222.

Gaard, E., Hansen, B., Olsen, B., Reinert, J., 2002. Ecological features and recent trends in the physical environment, plankton, fish stocks, and seabirds in the Faroe shelf ecosystem. p. 245–265. In: Sherman, K., Skjoldal, H.R., (Eds.), Large marine ecosystems of the North Atlantic. Amsterdam (NL): Elsevier Science..

Gaston, A.J., Jones, I.L., 1998. Birds families of the world. The Auks, Oxford University Press, Oxford.

Gaston, A.J., Woo, K., 2008. Razorbills (*Alca torda*) follow subarctic prey into the Canadian Arctic: colonization results from climate change?. *The Auk*, 125 (4), 939-942.

Glew, K.S.J., Wanless, S., Harris, M.P., Daunt, F., Erikstad, K.E. *et al.,* 2019. Sympatric Atlantic puffins and razorbills show contrasting responses to adverse marine conditions during winter foraging within the North Sea. *Movement Ecology*, 7, 33.

Grémillet, D., Charmantier, A., 2010. Shifts in phenotypic plasticity constrain the value of seabirds as ecological indicators of marine ecosystems. *Ecological Applications*, 20 (6), 1498-1503.

Harrison, P., Perrow, M.R., Larsson, H., 2021. Seabirds. The New Identification Guide. Lynx Editions, Barcelona, 600 pp.

Huettmann, F., Diamond, A.W., Dalzell, B., Macintosh, K., 2005. Winter distribution, ecology and movements of Razorbills *Alca torda* and other auks in the outer Bay of Fundy, Eastern Canada. *Marine Ornithology*, 33, 161-171.

Insley, S.J., Paredes, R., Jones, I.L., 2003. Sex differences in razorbill *Alca torda* parent - offspring vocal recognition. *Journal of Experimental Biology*, 206, 25-31.

Jones, T., Parrish, J.K., Peterson, W.T., Bjorkstedt, E.P., Bond, N.A. *et al.,* 2018. Massive mortality of a planktivorous seabird in response to a marine heatwave. *Geophysical Research Letters*, 45, 3193-3202.

Lavers, J.L., Jones, I.L., Diamond, A.W., 2007a. Natal and breeding dispersal of Razorbills (*Alca torda*) in Eastern North America. Waterbirds: *The International Journal of Waterbird Biology*, 30, 588-594.

Lavers, J.L., Jones, I.L., Diamond, A.W., 2007b. Impacts of intraspecific kleptoparasitism and diet shifts on razorbill *Alca torda* productivity at the Gennet Islands, Labrador. *Marine Ornithology*, 35, 1-7.

Moody, A.T., Hobson, K.A., 2007. Alcid winter diet in the northwest Atlantic determined by stable isotope analysis. *Marine Ornithology*, 35, 39-46.

Newton, I., 2010. Bird Migration; Collins: London, UK.

Ouni, R., Hamrouni, H., Nefla, A., Kilani, F., Foued, H. *et al.,* 2023. Action Pingouin *Alca torda*. Observation des oiseaux marins au large des côtes tunisiennes. ATVS, 71 p.

Ouwehand, J., Leopold, M.F., Camphuysen, C.J., 2004. A comparative study of the diet of guillemots *Uria aalge* and razorbills *Alca torda* killed during the *Tricolor* oil incident in the south-eastern North Sea in January 2003. *Atlantic Seabirds*, 6 (3/S.I.), 147-164.

Pasquet, E., 1988. Contribution à l'étude du régime alimentaire des guillemots de Troïl (*Uria aalge*) et petits pingouins (*Alca torda*) hivernant dans les eaux françaises. *Alauda*, 56 (1), 8-21.

Piatt, J.F., Sydeman, W.J., Wiese, F., 2007. Introduction: a modern role for seabirds as indicators. *Marine Ecology Progress Series*, 352, 199-204.

Ryan, P.G., Avery, G., Rose, B., Ross, G.B., Sinclair, J.C. *et al.,* 1989. The Southern Ocean seabird irruption to South African waters during winter 1984. *Marine Ornithology*, 17, 41-55.

Singh, N.S., Bamon, I., Dixit, A.S., Sougrakpam, R., 2015. Structural variations and their adaptive significances in the bones of some migratory and resident birds. *The Journal of Basic & Applied Zoology*, 70, 33-40.

St John Glew, K., Wanless, S., Harris, M.P., Daunt, F., Erikstad, K.E. *et al.,* 2019. Sympatric Atlantic puffins and razorbills show contrasting responses to adverse marine conditions during winter foraging within the North Sea. *Movement Ecology*, 7 (1), 1-14.

Swennen, C., Duiven, P., 1977. Size of food objects of three fish-eating seabird species: *Uria aalge*, *Alca torda* and *Fratercula arctica* (Aves, Alcidae). *Netherlands Journal of Sea Research*, 11, 92-98.

Tanhua, T., Hainbucher, D., Schroeder, K., Cardin, V., Álvarez, M. *et al.,* 2013. The Mediterranean Sea system: A review and an introduction to the special issue. *Ocean Science*, 9, 789-803.

Teixeira, A.M., 1986. Razorbill *Alca torda* losses in Portuguese nets. *Seabird*, 9, 11-14.

Thibault, M., Houlbrèque, F., Lorrain, A., Vidal, E., 2019. Seabirds: Sentinels beyond the oceans. *Science*, 366 (6467), 813-813.

Tiralongo, F., Russo, F., Colombo, M., 2019. From scuba diving to social networks: A curious association between two small fish species, *Lepadogaster candolii* Risso, 1810 and *Parablennius rouxi* (Cocco, 1833), and *Muraena helena* (Linnaeus, 1758) coming from citizen science. *Regional Studies in Marine Science*, 29, 100648.

Tuck, L.M., 1961. The murres: their distribution, populations and biology-a study of the genus *Uria.* Canadian Wildlife Service Monograph Series No. 1. Ottawa: Canadian Wildlife Service.

Viola, B.M., Sorrell, K.J., Clarke, R.H., Corney, S.P., Vaughan, P.M., 2022. Amateurs can be experts: A new perspective on collaborations with citizen scientists. *Biological Conservation*, 274, 109739.

Ward, E.J., Marshall, K.N., Ross, T., Sedgley, A., Hass, T. *et al.,* 2015. Using citizen-science data to identify local hotspots of seabird occurrence. *PeerJ*, 3, e704.

Zhao, Y., Li, Y., 2022. Impact of fisheries footprint on an early warning indicator of resilience reduction in marine net primary productivity. *ICES Journal of Marine Science*, 79, 2741-2751.

Supplementary Material

The following supplementary material is available for this article:

Fig. S1: Razorbill biometric measures. Schematic representation of biometric measures of the head and the bill, measured with a digital calliper (± 0.01 mm). HL is for the head length (dashed line); BL for bill length (dash-dotted line) and BD for bill depth (dotted line) measured at the gonys (cfr. Material and methods – to be referred also to Table 2). Razorbill picture is by © Michelangelo Ambrosini.

Table S1. List of Razorbill food items in the Mediterranean Sea during winter 2022/2023. Data type, country, region, location (when available) and date for each record are reported. Food items have been identified at the lowest taxonomic level possible.