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The negative effect of dredging and dumping on shorebirds at a coastal wetland in northern Spain

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ABSTRACT

Dredging and/or dumping actions at coastal environments are a common phenomenon worldwide. The re-working of dumped sediments from their disposal sites to places of great ecological value can have a very strong impact on the ecosystems through deep changes over the communities and the trophic web. Using a relevant dredging-dumping episode carried out in 2003 at Urdaibai, one the chief estuary areas in northern Iberia, we tested the consequence of this action on the subsequent use of the zone by shorebirds. The surface sediment characteristics before and after the dredging and dumping actions were also compared. The dredging at Urdaibai showed a negative effect on bird abundance in three out of the eight species tested overall (dunlin, grey plover, common ringed plover). Highest-ranked models supported a decrease in their population sizes two years after the event. In this scenario, local authorities should be appealed to take dredging and dumping effects into account in order to improve the estuary management.

1. Introduction

All ecosystems are subject to some degree of perturbation, and all organisms are well adapted to cope with predictable perturbations, such as those determined by seasonal events. However, extreme or unpredictable perturbations, either natural (e.g. hurricanes) or owing to human activity (e.g. fires), could cause severe effects on ecosystems, from which it might take decades to recover (Borja, Dauer, Elliott, & Simenstad, 2010; Manning et al., 2011; Pons & Clavero, 2010).

The conservation of intertidal coastal environments is today a major concern for ecologists, managers, and the society in general (Ma, Cai, Li, & Chen, 2010; Weller, 1999). Habitat loss and degradation are part of a problem that affects many intertidal wetlands all over the world (Bildstein et al., 1991; Eddleman, Knopf, Meanley, Reid, & Zembal, 1988). For instance, the global annual loss rate of coastal salt marshes is calculated to be 1–2% per year (Duarte, Dennison, Orth, & Carruthers, 2008), a rate which is above of the 0.5% per year loss rate of tropical forests (Achard et al., 2002).

Many intertidal coastal environments, mostly those linked to estuaries, have been historically used as natural harbours, an activity that is often associated with constant or periodic dredging in order to keep or increase the depth of these water bodies (Bary, Bates, & Land, 1997). The material (clay, sand or mud) extracted during such dredging is often dumped close to the dredging area to minimize the economical cost of the transport (Bary et al., 1997). One of the main consequences of dredging and dumping actions is habitat burial or destruction, with a negative impact on the ecosystem, especially on the macrobenthos that is situated in the bottom of the trophic network (Boyd, Limpenny, Rees, & Cooper, 2005; Erftemeijer & Lewis, 2006; Lewis, Weber, Stanley, & Moore, 2001; Lindeman & Snyder, 1999). Thus, any negative effect on such communities can alter the entire trophic structure related to the mudflats and, consequently, induce negative effects on upper trophic levels.

Clayey-muddy and sandy substrates do not host the same communities of macrobenthos that constitute the food of many shorebirds (Colwell, 2010). In general, mudflats are commonly richer in shorebird food than sandy areas (Burger, Niles, & Clark, 1997). Dredging and dumping actions carried out in estuary areas often cause habitat loss in very ecologically-sensible habitats, such as mudflats (Monge-Ganuzas, Cearreta, & Evans, 2013). Thus, dumping of sand in some sensitive estuarine areas where there is an

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active sediment transport could cause a coverage of the mudflats and, consequently, long-lasting negative effects on benthic communities, as well as severe negative consequences for shorebirds using these areas (Piersma et al., 2001).

Here, we used retrospective analyses of dredging episodes on shorebirds' abundance and diversity in a tidal marsh, which could help to identify the consequences of dredging on shorebirds using the marsh. We predicted that relevant dredging and dumping actions may lower the capacity for shorebird populations to recover. To test this we used long-term data of shorebird censuses conducted in a site (an intertidal coastal environment located at the Urdaibai Biosphere Reserve, northern Spain) affected by a very important dredging and dumping episode. Together with this analysis, we also compared induced surface grain size trend before and after the dredging and dumping episode. We also predicted that the effect of the dredging and subsequent dumping episode should have been more severe on those species that forage mostly or only on the mudflats.

2. Material and methods

2.1. Study area

The Urdaibai estuary is a coastal wetland located in the North of Spain. It was declared Biosphere Reserve in 1984, included within the Ramsar list in 1992, and SPA (ES0000144) and SAC (ES213007) of Natura 2000 in 2014. With ca. 945 ha, Urdaibai is used by a remarkable amount of mostly northern Euro-Siberian waterbirds (including shorebirds) that use this area either as a stopover site during migration period or as a wintering area (Galarza, 1984; Garaita, 2012). Shorebirds constitute a group of birds with conservation interest within the region (Galarza & Domínguez, 1989; Hidalgo & Del Villar, 2004). Urdaibai has suffered periodic dredging and dumping actions for the last 43 years (Monge-Ganuzas et al., 2013), with the last action occurring in 2003, when 243,000 m^3 were extracted from the main channel of the estuary and dumped in a sandy area close to the mouth. In comparison with previous dredging episodes, this last was very much larger (e.g. ca. 310% higher than the previous dredging in 1998–1999). After this dredging, wave winter storms together with tidal wave action progressively eroded the sediment and spread some sand towards upper estuary areas (Monge-Ganuzas, Cearreta, & Iriarte, 2008) over much of the existing intertidal mudflats, the main foraging area for shorebirds within the estuary (Hidalgo & Del Villar, 2004).

2.2. Data collection

In March 2003 (immediately before the dredging and dumping carried out at Urdaibai), 24 surface sediment samples were collected either by hand all along the main intertidal mudflats or from a 4 m-long vessel by a Van Veen grab (this last used to take samples along the chief estuary channel). Overall, the sampling net consisted in a 200 m each side orthogonal grid (Fig. 1). This sampling protocol was repeated in July of 2016. Samples were stored until their analysis in a laboratory (UPV/EHU).

Using a Laser diffraction particle size analyzer (Beckman Coulter counter LS 13 320), three replica of each sediment sample were analyzed (Nayar, Miller, Hunt, Goh, & Chou, 2007) and statistically integrated in order to obtain the weight percentage grain size distribution for each sample (Udden, 1914; Wentworth, 1922).

Census data consisted in counts (species and numbers of shorebirds) conducted during a single survey day in mid-January, coordinated by Wetlands International. Here, we considered a period spanning from 1992 to 2011. Censuses were conducted using a fixed, standard protocol, consisting in counting always from the same points, covering the same survey area and, if possible, by a same observer from year to year, during high tide. In general, due to the characteristics of Urdaibai, where birds accumulate in relatively small areas easy to survey during high tide (J. Arizaga, pers. obs.), high tide-census are recommended for counting waterbirds (but see Navedo, Masero, & Juanes, 2007).

Meteorological data (mean value for the daily mean temperatures in January) were extracted from the NOAA website (www.esrl.noaa.gov). We considered an effect of temperature because local numbers of waterbirds within the region can depend on climatic conditions at a local scale level (Navedo et al., 2007).

2.3. Data analyses

Sediment characteristics (percentage of sand and silt-clay of each sample) before and after the dredging and dumping actions at Urdaibai were compared with a *t*-test for repeated measures.

With the aim of conducting models on counts we selected those species which showed a median ≥10 individuals/year for the period spanning from 1992 to 2003 (i.e., before the dredging and dumping episode of 2003). This provided us a list of only 8 species of shorebirds to be considered within statistical models: dunlin *Calidris alpina*, purple sandpiper *C. maritima*, common ringed plover *Charadrius hiaticula*, Eurasian curlew *Numenius arquata*, grey plover *Pluvialis squatarola*, green redshank *Tringa nebularia*, common redshank *T. totanus*, Northern lapwing *Vanellus vanellus* (Fig. 2). Because of their trophic ecology these shorebirds may not depend on the mudflats in the same way, since some of them also (or mostly) forage in other habitat types (e.g. Northern lapwing, Eurasian curlew), such as the prairies and pastures surrounding Urdaibai (Navedo et al., 2013).

Moreover, we also calculated for each year the shorebird species diversity. We used for that the Shannon index (H'). It accounts for both abundance and evenness of all recorded species, and was calculated as: $H' = -\Sigma(p_i \times \ln p_i)$, where p_i is the proportion of species i relative to the total number of species (R, richness) (Magurran & McGill, 2011).

Data were analyzed using Generalized Linear Models (GLMs). Bird counts (abundance) of each species were used as object variable. We used the log-linear link function with negative binomial distribution errors for the GLMs due to the nature of the object variable (counts with over-dispersion). Additionally, we also conducted GLMs with H' as an object variable. In this case we used a linear link function with Gaussian errors. Overall, we considered four possible different explanatory variables: year (considered as a linear variable to test for log-linear trends in shorebird abundance), temperature (as a linear variable) and two effects that correspond to different responses of the shorebirds to the dredging episodes (for details see Table 1).

All possible models were ranked according to their small-sample size corrected Akaike (AICc) values (Burnham & Anderson, 1998). Models differing in less than 2 AICc values were considered to fit to the data equally well (Burnham & Anderson, 1998). In these cases, model averaging was carried out.

All analyses were run with R (R Core Team, 2014), and the "lme4" (Bates et al., 2014) and "MuMIn" (Barton, 2014) packages. Package "lme4" allows us to run GLMMs and "MuMIn" is used to calculate AICc values and for the model averaging procedure.

3. Results

The percentage of sand within the estuary was observed to increase very significantly (Table 2). Along a north-south gradient, the sediment was richer in sand in the north but note the difference before and after the dredging and dumping of 2003 (Fig. 3).

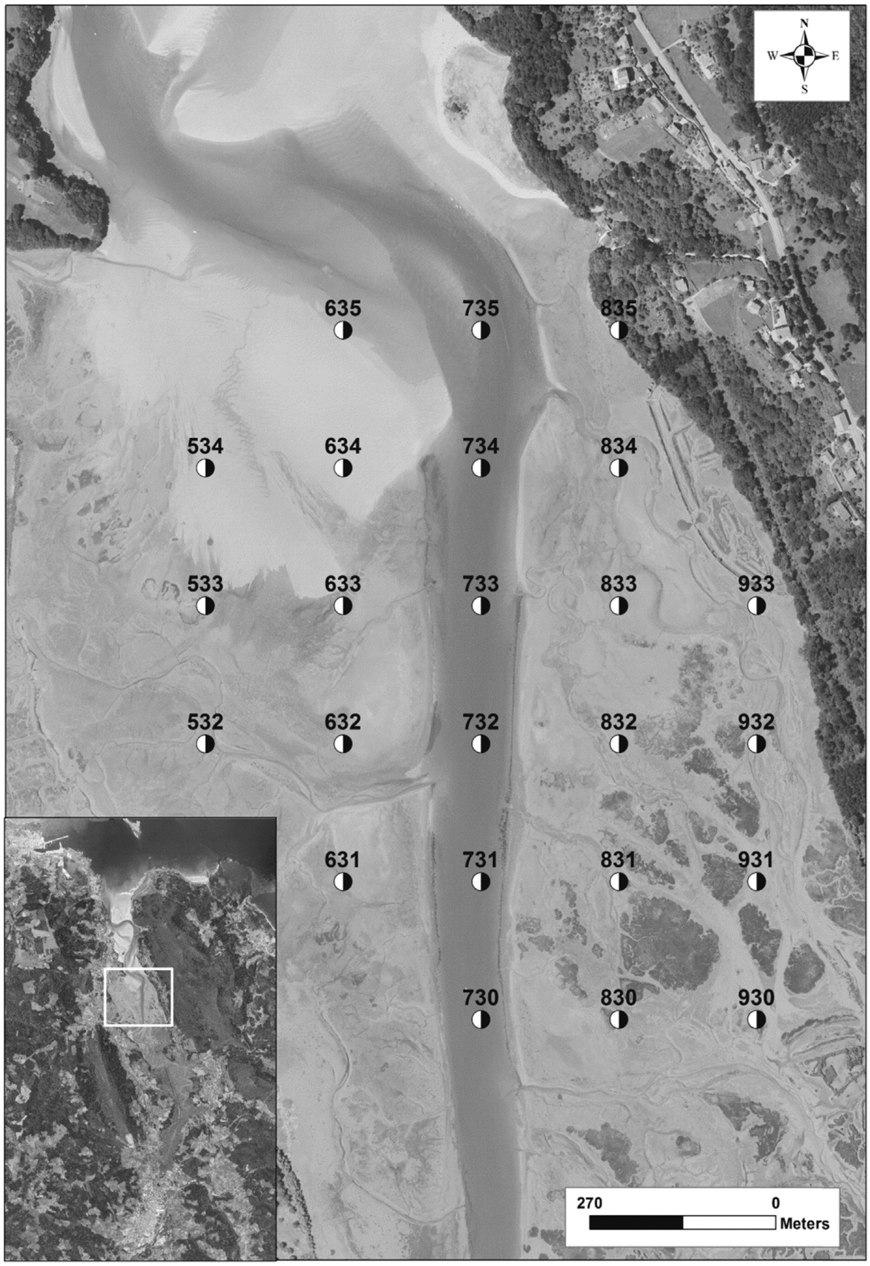

Fig. 1. Location of the sampling points considered to sample sediment characteristics all along the intertidal mudflats at Urdaibai.

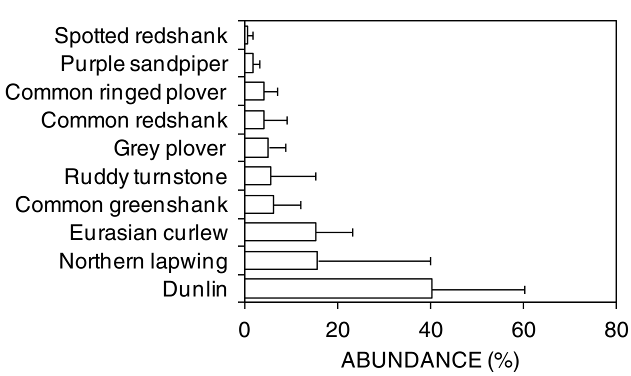

Fig. 2. Relative abundance (mean ± SD) of the ten most abundant shorebirds that overwinter at Urdaibai, period 1992–2011. Ruddy turnstones and spotted redshanks showed a median population size <10 individuals per winter for the period 1992–2003, and were not included in the analyses.

Table 1
Biological meanings of the models run for each species. Abbreviations.

Models	Meaning
1. Null	Population size is constant (or fluctuates from year to year but without any particular non-random effect).
2. 2004–2011	The impact of the dredging one year after the event (i.e., from 2004 onwards) is expected to have an effect on shorebird abundance.
3. 2005–2011	The impact of the dredging two years after the event (i.e., from 2005 onwards) is expected to have an effect on shorebird abundance
4. Year	Population size co-varies log-linearly with year.
5. Temp	Population size co-varies with the mean winter (Jan.) temperature.

We also ran four additional models by adding "temp" (additive effect) to models 2–4. Overall, therefore, 8 models were tested.

Table 2
Mean (±95% confidence interval) percentage of sand and mud in 25 sampling points situated all along the mudflats at Urdaibai before and after the dredging and dumping episode carried out in 2003. The percentage of gravel was zero for all samples.

Type of sediment	2003 (before)	2016 (after)	*t*-Test (*P*)
Sand	38.3 ± 9.9%	64.2 ± 10.4%	4.814 (<0.001)
Mud	61.5 ± 10.1%	35.8 ± 10.4%	4.704 (<0.001)

Table 3
Ranking of the top four best-ranked models obtained for each species and the species diversity (*H'* index) in relation to their small sample size-corrected Akaike values (AICc). ΔAICc: difference in AICc values in relation to the top model. Model abbreviations as in Table 1.

Models	AICc	ΔAICc	AICc weight
Dunlin			
Null	69.1	0.0	0.38
[2005–2011]	71.0	1.9	0.14
[2004–2011]	71.2	2.1	0.14
Year	71.3	2.2	0.13
Northern lapwing			
Null	59.1	0.0	0.39
Temp	60.9	1.8	0.15
[2004–2011]	61.3	2.2	0.12
[2005–2011]	61.6	2.5	0.11
Eurasian curlew			
Null	66.3	0.0	0.41
[2005–2011]	68.7	2.4	0.13
[2004–2011]	68.7	2.4	0.12
Temp	68.7	2.4	0.12
Common greenshank			
Null	61.2	0.0	0.42
Year	63.6	2.4	0.13
[2004–2011]	63.7	2.5	0.12
[2005–2011]	63.7	2.5	0.12
Grey plover			
[2005–2011]	58.8	0.0	0.27
Year	59.4	0.6	0.20
[2004–2011]	59.6	0.7	0.18
Null	60.0	1.2	0.15
Common redshank			
Null	61.2	0.0	0.42
Year	63.6	2.4	0.13
[2004–2011]	63.7	2.5	0.12
[2005–2011]	63.7	2.5	0.12
Common ringed plover			
Null	59.5	0.0	0.32
[2005–2011]	60.8	1.3	0.17
Year	60.9	1.4	0.16
[2004–2011]	61.1	1.6	0.14
Purple sandpiper			
Null	54.5	0.0	0.43
Year	57.0	2.5	0.12
Temp	57.0	2.5	0.12
[2005–2011]	57.0	2.5	0.12
Diversity index			
Null	6.2	0.0	0.41
Temp	8.1	1.9	0.16
[2004–2011]	8.8	2.6	0.12
[2005–2011]	8.8	2.6	0.11

The null model was the model best fitting data in seven out of the eight species tested overall (Table 3). However, in two of such species (dunlin, common ringed plover), models assuming an impact of the dredging and dumping were equally well supported. In another species (grey plover), the top model was the one assuming an effect of the dredging two years after it occurred (Table 3). Thus, overall, there were three species for which the dredging and dumping episode had an impact on their population sizes (Fig. 4). In addition, Northern lapwing population numbers and the diversity index were found to be affected by temperature (Table 3), although this effect was non-significant after model averaging (Table 4).

Table 4
Coefficients (*B*-parameter estimates ± SE) of best models (ΔAICc < 2) from Table 2 Abbreviations as in Table 1; (ns), non-significant coefficient. Model averaging was carried out when there were two or more models with an AICc < 2 in relation to the top model (but see comments[b] and[c]).

Species	Intercept	[2005–2011][a]	Temp
Dunlin	+0.888	−0.327	
Northern lapwing	+0.574		−0.187 (ns)
Eurasian curlew	+0.666		
Common greenshank	+0.381		
Grey plover[b]	+0.575	−1.318	
Common redshank	+0.275		
Common ringed plover[c]	+0.324	−0.706	
Purple sandpiper	−0.026		
Diversity index (*H'*)	+1.403		+0.040 (ns)

[a] Reference value (*B* = 0): period 1992–2004.
[b] Coefficients only from the top model, since the other models included alternative (but not additive) effects.
[c] Coefficients only after averaging model one and two, since the other models included alternative (but not additive) effects.

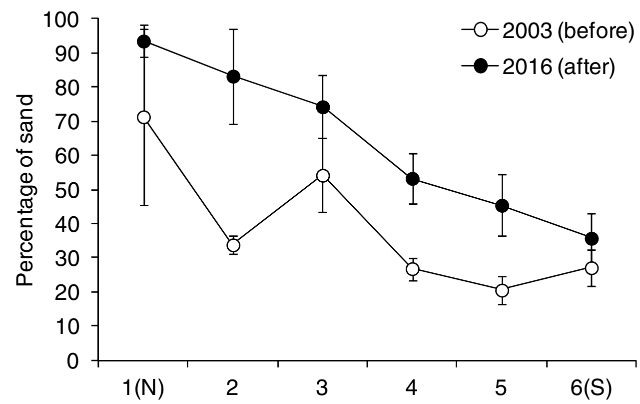

Fig. 3. Mean (±SE) percentage of sand along a north-south axis (1 stands for the sampling points 635–835; 2 for the points 534–834, etc.) of those samples taken to characterize the sediment of the intertidal mudflats at Urdaibai.

In those species where there was an effect of the dredging the higher-ranked model was the one where the response was observed to occur two years after the dredging (Table 3).

4. Discussion

Dredging and dumping actions at coastal environments is a common phenomenon worldwide. The movement of sediments of different nature and its re-location in places of great ecological value can produce, however, a strong impact on the ecosystems through deep changes in the communities and the trophic nets (Sarda, Pinedo, Gremare, & Taboada, 2000; Vanaverbeke, Deprez, & Vincx, 2007). Quite often, these activities have dramatic effects on benthic communities (Powileit, Kleine, & Leuchs, 2006), with consequences at upper trophic levels. Using a relevant dredging episode carried out at one the chief estuary areas from northern Iberia, we observed a decrease in population size of several shorebird species which depended on mudflats to forage just one or two years after this event.

Although dredging and dumping in Iberian estuaries is common, unfortunately we have no evidence of available local information about their impact on shorebird assemblages. In a broader context, however, it is well known that dredging can have a severe negative impact on shorebirds as population size of bivalves or other potential prey is reduced, either because direct sediment extraction at foraging places (Lewis et al., 2001; Piersma et al., 2001) or because these feeding grounds are covered with sediments re-

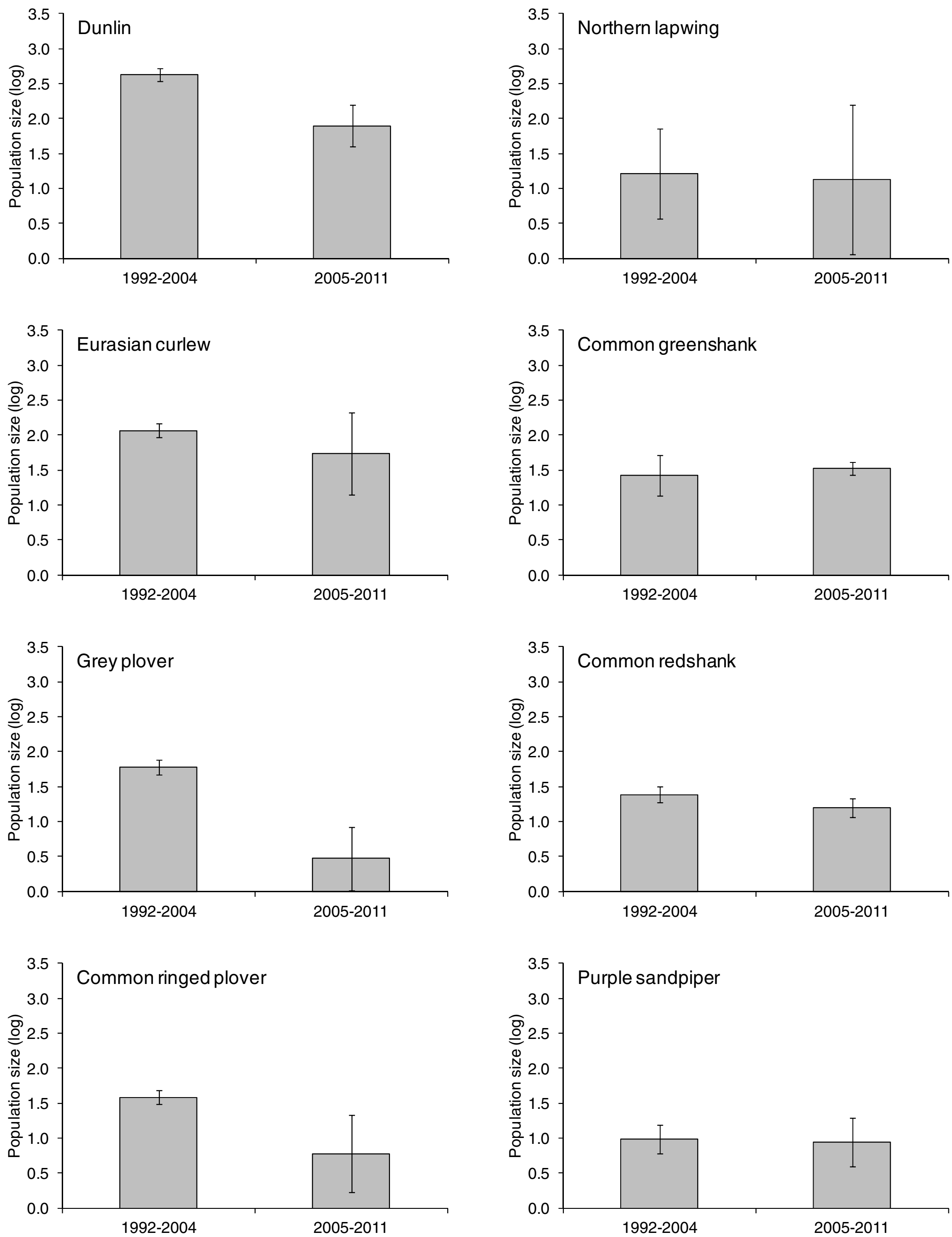

Fig. 4. Mean (±95% confidence interval) population size (log-transformed) of shorebirds before and after the dredging and dumping actions of 2003 at Urdaibai, in northern Iberia.

worked from dumping sites that alter invertebrate populations, as surely occurred at Urdaibai. The fact that the diversity of shorebirds remained constant at Urdaibai despite changes in abundance after the dredging and dumping episode of 2003 suggests that the most abundant species were similarly affected.

Although food availability was not analyzed at our study sites our results would support the idea that the sand covering of the mudflats had a dramatic change on the macrobenthos that should be transferred to upper trophic levels (Boyd et al., 2005). Our results also show that the effect was very fast: the population size of some of the species was observed to decrease just two years after the dredging and dumping actions (with some models even also supporting an affect just a single year after the event).

Interestingly, and as predicted, Northern lapwing numbers, as well as those from other species less-dependent on marshes to forage at Urdaibai were independent from the dredging from 2003. Northern lapwings or Eurasian curlews feed mostly in the pastures and cultivations existing around the estuary and, therefore, are little affected by dredging episodes at these wetland sites. Some shorebirds, indeed, seem to benefit from foraging in farmland habitats (Navedo et al., 2013), even if these would be subject to intensive farming practices (Lindström, Danhardt, Green, Klaassen, & Olsson, 2010). Model selection process supported that Northern lapwings showed strong inter-annual fluctuations associated to winter temperatures at a local scale, although this effect was non-significant after model averaging, probably due to the high over-dispersion of data. The presence of this species in southern Europe is well reported to be highly stochastic (Tellería et al., 1996), and is mostly associated to dominant meteorological conditions during the winter in central Europe (SEO/BirdLife, 2012). Presented results partly support the idea that the population that spends the winter in northern Iberia increases with decreasing temperatures.

The specific variable effect of temperature on bird abundances (with a positive effect in some shorebirds and a negative effect in others) along the coast of the Bay of Biscay was also reported by Navedo, Masero, and Juanes (2007). A positive effect of temperatures on local numbers could be associated to better survival during warmer winters either due to higher food availability (Yasué, Quinn, & Cresswell, 2003) or to lower thermoregulation costs (Ketersen & Piersma, 1987). However, local abundances of other species would be shaped by decreasing temperatures, probably associated to displacements to the coastal marshes of the Bay of Biscay from colder regions situated further north or inland (Galarza & Tellería, 1985).

Resilience is the capacity of an ecosystem to tolerate perturbation without switching to an alternate state (Standish et al., 2014). Urdaibai has been subject to recurrent dredging during the last 43 years. It may be that dredged material is re-worked by the tide and wave induced currents, and this may allow the recovering of the system morphology after some years (Monge-Ganuzas et al., 2013). However, even if a system could recover after a perturbation, recurrent perturbations may lower its capacity for recovering over the long-term (Díaz-Delgado, Lloret, Pons, & Terradas, 2002). Noteworthy, we observed that even in 2016, i.e. 13 years after the dredging and dumping actions carried out in 2003, the percentage of sand within the sediment have passed from a mean of 38–64%, with this percentage decreasing across a north-south axis (i.e., from the site where the sediment was dumped towards upper estuary areas). This result suggests that the estuary has been unable to come back to an original state before the dredging and dumping episode and it may be discussed to what extent this effect is reversible, at least short- to medium-term. The action of the waves and tide, together with the increase of the sea level (assessed to be 2 mm/year) (Leorri, Cearreta, García-Artola, Irabien, & Blake, 2013), will probably strengthen this covering of the existing mudflats by sand during next years, hence it is unlikely to expect a recovering of shorebird abundance at these areas in Urdaibai.

In this scenario, local authorities should be appealed to take the dredging and dumping effects into account in order to improve the Urdaibai estuary management because this wetland is, in fact, an important Ramsar and Natura 2000 site managed by a Governing Board composed by most regional public administrations (Basque Government, Bizkaia Council, municipalities, etc.). Dredging activities at Urdaibai were authorized or reported by a number of public administrations, including the Basque Government (Environment Department), Bizkaia Council, Basque Water Agency and the Ministry of Environment of Spain, attending to their competences. As a part of the Urdaibai Governing Board, all such public authorities should take into consideration both the dredging and dumping effects and either promote alternative solutions or limitations to this activity if it is incompatible with the preservation of the mudflats and the occurrence of shorebirds within the area and, overall, the conservation and proper management of this wetland.

Given the sedimentary connection between the best disposal areas and the mudflats at Urdaibai probably the best decision may be to forbid both the dredging and dumping due to their dramatic consequences for the ecosystem. For instance, at Odiel estuary, in southern Iberia, dredging material is dumped in areas apart from intertidal mudflats, creating good conditions for the breeding of some species like the little tern *Sternula albifrons*, Kentish plover *Charadrius alexandrinus* and the collared pratincole *Glareola pratincola* (J. A. Amat, pers. obs.). Given the size and territory use at Urdaibai, however, these sites would be hardly available hence apparently there would be no place to dump the material extracted during dredging actions.

In conclusion, we obtained statistical data support that suggest that a strong dredging and dumping episode carried out at Urdaibai resulted in a covering of existing mudflats by sandy sediment which promoted a decrease of the population size of a number of shorebird species wintering in this area. This effect was much clearer in species more dependent on mudflats to feed, but had an apparent null impact in shorebirds that also or mainly forage in other habitat types. Thus, it is highlighted that the management of the dredging and dumping activities at Urdaibai should be improved by taking into consideration the conservation of shorebirds, among other waterbird species.

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