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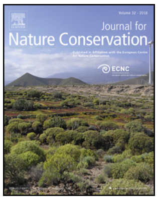

The negative effect of dredging and dumping on shorebirds at a coastal wetland in northern Spain

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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 $\geq$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).