The North Mudflat of the Seine Estuary: How Much Surface Needs To Be Restored?

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Abstract: For the last 30 years, the Seine estuary has been one of the most studied north-eastern Atlantic estuaries in terms of the benthos, fish and bird communities and is one of the most affected by human activities. The Seine's North mudflat plays an important role as a nursery for several commercial fish, such as sole and sea bass. The benthic prey living in the mudflat also constitute an essential nutritional resource for shorebirds and anatids throughout the year, and for migrant species during especially cold winters. However, the mudflat's surface has decreased dramatically over time—from 760 ha in 1978 to < 290 today—due to natural silting up and successive construction projects, such as the latest Normandy Bridge and the new Port 2000. This study analyzes the relationships between the temporal changes of the mudflat surface and the changes in the three biological compartments with respect to abundance, trophic structures and ecological guilds. Only bird abundance has decreased significantly with the reduction of the mudflat's surface. Both benthos and fish abundances are highly variable, and thus cannot be connected to the changes in the surface area. Mudflat surface has been re-created with success as compensatory measures after the two last constructions. However, the amount of surface that needs to be restored in the future remains debatable. Still, something must be done since, at the current rate of reduction, the lower part of the North mudflat could disappear entirely over the next 20 years if an active restoration policy is not instituted.

Key words: Estuaries - fragmentation - land use change - identifying appropriate conservation and restoration objectives - restoration of wilderness areas

Introduction

Anthropogenic influence in the Seine estuary began early—mid 19th century—and continues to this day. The estuary's ecosystems have become more fragile as a result of this human activity, which has led to the extreme compartmentalization of the biological units and the drastic reduction of the intertidal zones downstream, with a loss of more than 100 km² between 1850 and the present day (Avoine, 1994; Cuvilliez et al., in press). The recent Port 2000 extension in Le Havre (2000-2005) has seriously affected the morphological and sedimentary evolution of the downstream section of the estuary, but also contributes to changes in the estuary habitats and populations (Dauvin, 2006). The estuary habitat, as defined in the Habitats Directive, has been directly affected by the successive modifications in the lower part of the Seine estuary, and the intertidal mudflats, especially the North mudflat, have decreased dramatically in surface (Hamm et al., 2001). Nonetheless, this mudflat continues to play an important role due to its high benthic production (Dauvin & Desroy, 2005) and the biomass transfers to fish (Morin et al., 1999) and birds (Le V. Dit Durell et al., 2004).

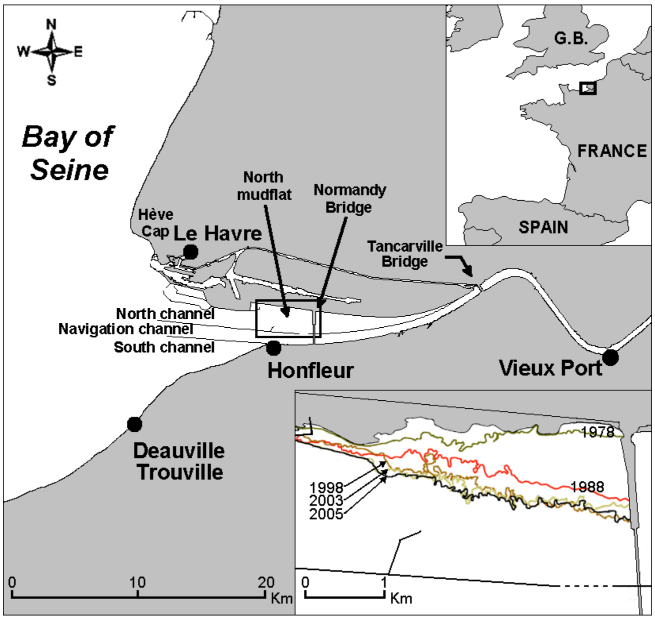


Figure 1. Location of the North mudflat and evolution of its limits from 1978 to 2005.

The objectives of this study of the Seine estuary's North mudflat (Figure 1) are to quantify the evolution of surfaces over the last three decades and to estimate the changes in the estuarine functions related to this mudflat in order to determine the surface that would reasonably be necessary to restore its initial biological functions. This research combines two elements—a new method for estimating the functional capacities of the nursery on the mudflat, the carrying capacity of the macrobenthos and the transfer of benthic production towards higher trophic levels (fish and birds); and a census of geo-morphological and biological knowledge—to determine both the minimal and the optimal surface that this mudflat should have in order to ensure its estuarine functions.

Materials and methods

Methodology: Rather than generating a trophic model for the whole Seine estuary, as proposed by Rybarcyck & Elkaim (2003), the approach used in this study is similar to the one proposed by the Ecosystem Management Research Group (ECOBE) for its work in restoring the biological functions in the Scheldt estuary (Van Damme and Meire, 2006; personal communication). The underlying principle of the approach is that, since the benthic compartment is the foundation of the trophic network for fish and the birds, it is necessary to preserve the benthic habitat in order to maintain a certain benthic biomass. Thus, it follows logically that to sustain estuarine functions, including the trophic capacities and functions needed by birds and fish, and to maintain the bird reception capacities (i.e., providing them a resting place), it is necessary to determine the surface of mudflat needed to maintain that certain benthic biomass.

According to ECOBE (Van Damme & Meire, 2006), BBref x Sref = BBn x Sn, where BBref= reference benthic biomass; Sref = reference of mudflat surface area; BBn = needed benthic biomass and Sn = needed mudflat surface area. The aim is to determine the mudflat surface needed to reach a given functional level for each of the estuarine functions, possibly by calculating the benthic biomass necessary to maintain this level.

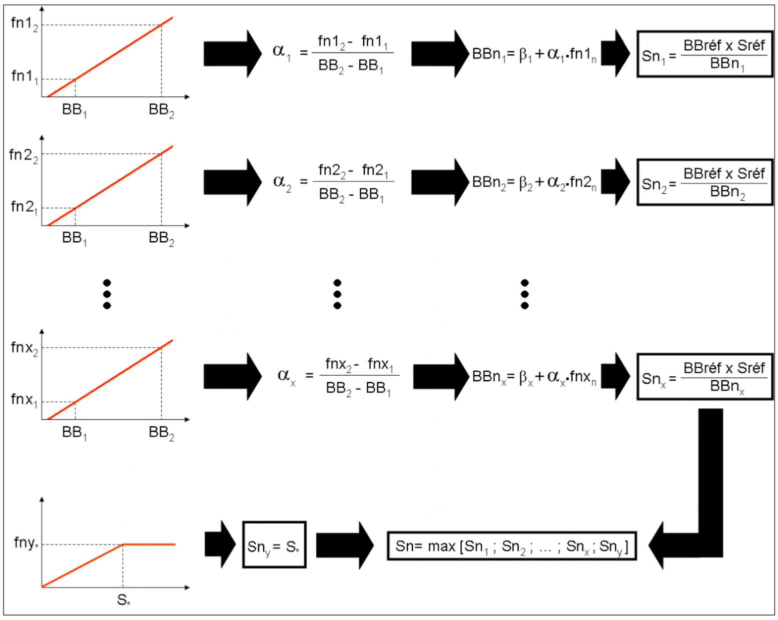


Figure 2 summarizes the different steps of the method : it is necessary to know the surface of the intertidal mudflat in m², the abundances and density (i.e., number of individuals per m²) of the benthic organisms and their characteristics (e.g., mean individual biomass and trophic groups), the abundances of the birds using the mudflat and their characteristics (e.g., trophic regime), the abundances of the fish using the mudflat and their characteristics (e.g., feeding mode, migratory behaviour) and the surface temperature of the sea.

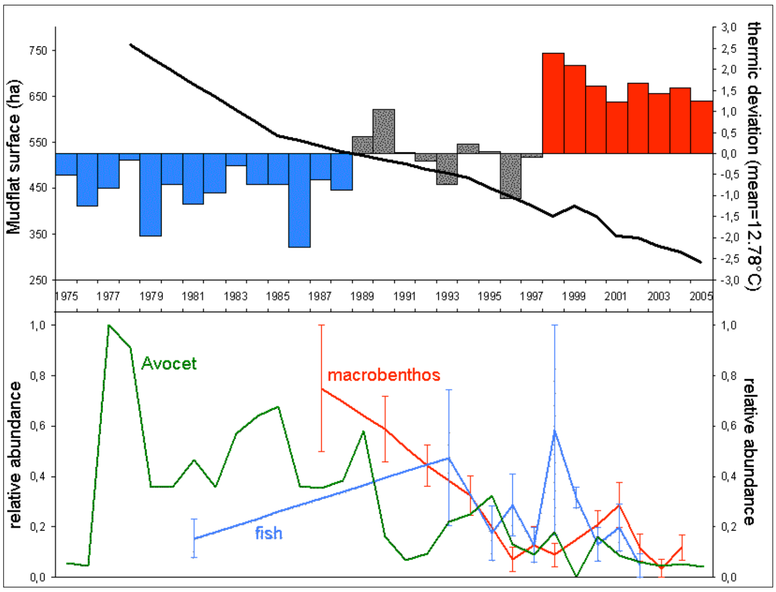
Figure 2. Methodology used for the determination of the surface of the North mudflat needed for the estuarine functionalities.

Data available: *Surface area data.* Aerial photographs were used to estimate the temporal changes of the coastal mudflat and mudflat area (downstream from the Normandy Bridge) from 1967 to 2006, especially for five main periods (1978 - 1988 - 1998 - 2003 - 2005) in which the limit of the tidal flats can be situated exactly (Figure 1).

Benthic data. Data concerning 330 samples taken from 1980 to 2004 were extracted from MABES 2 database (GIP Seine-Aval; nbacq@seine-aval.fr). However, due to the different mesh sizes (0.5 mm vs. 1 mm) and only sample for 1995, benthic data was only available for the periods 1987-1994 and 1996-2004. In this data, forty taxa were found. The most frequently found species were: the polychaetes *Nereis (Hediste) diversicolor* and *Manayunkia aestuarina*, the bivalves *Macoma balthica*, *Cerastoderma edule* and *Scrobicularia plana*, the gastropod *Hydrobia ulvae*, the amphipod *Corophium volutator* and the oligochaete tubificidae.

Ornithological data. Seven birds—the avocet *Recurvirostra avosetta*, the Eurasian curlew *Numenius arquata*, the common redshank *Calidris alpina*, the bar-tailed godwit *Limosa lapponica*, the ringed plover *Charadrius hiaticula*, the common shelduck *Anas acuta* and the northern pintail *Tadorna tadorna*—are known to feed on the Seine's North mudflat. The parameters available for each species are the winter abundances (December-January, 1977-2006) and the annual maximum abundances (1975-2006). The winter abundances were compared at the national and international scales with the Wetlands International records, which revealed that the reduced abundances of the common shelduck, the duck pintail and the avocet are the only ones specific to the Seine.

Fish data. Most of the fish data used in this study came from the IFREMER (Port-en-Bessin). The samples were collected from 1995 to 2002 with a beam trawl, following a first campaign in 1981 (Duval, 1982). Some supplementary data from the *Cellule du Suivi Littoral Normand* (Normandy Coastal Monitoring Cell) in Le Havre were also used. These supplementary data were recorded before the construction of the Normandy Bridge; samples were taken in 1988, 1990 and 1993 with bottom trawls. The data for 14 fish—the European eel *Anguilla anguilla*, the rockling *Ciliata mustela*, the herring *Clupea harengus*, the sea bass *Dicentrarchus labrax*, the gobies, the whiting *Merlangius merlangus*, the smelt *Osmerus eperlanus*, the flounder *Platichthys flesus*, the plaice *Pleuronectes platessa,* the common sole *Solea solea*, the sprat *Sprattus sprattus*, the pipefish *Syngnathus*



spp, the tub gurnard *Trigla lucerna*, the pouting *Trisopterus luscus* and brown shrimp *Crangon crangon*—were analyzed to determine the evolution in their parameters. The available data from the gear used are not densities but density indices. Consequently, when the values of these indices are multiplied by the surface of the mudflat, the results are indices of abundance and not real abundances.

Figure 3. Temporal evolutions of mudflat surface (curve), SST (histograms), and three biological compartiments.

Temperature data. The average monthly SST (±0.01°C) at 50°N/0.0°E were extracted from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) for the period from 1975 to 2005. The analysis of these temperatures revealed a warming of the water over this period, with an abrupt increase in 1998 (Figure 3).

Results and discussion

As Figure 1 shows, the surface of mudflat has decreased dramatically over the last 30 years, although the eastern and western sections of the mudflat appear to have suffered much less erosion than the central zone. There is a highly significant linear relationship between the mudflat's surface and time ($r^2 = 0.9719$). This relation permits the mudflat surface to be inferred for the years without observed data. Still, it is possible that the mudflat surface has evolved towards an asymptote with at least two residual surfaces: one close to the bridge and another in the hook near the north dike. Based on this evolution, it is realistic to predict that the mudflat will have completely disappeared downstream of the Normandy Bridge by the end of 2023 if nothing is done to change the situation.

he benthic data and the fish data both show very strong intra- and inter-annual variability's. The majority of the benthic and fish functions exhibit variation coefficients higher than 100%, with a higher-than-average standard deviation. This is primarily due to several data problems. First of all, the data used here were not gathered according to the same protocol over time. In addition, the stations were not chosen specifically for this study, and thus their numbers and locations could change depending on the year. To reduce this problem, we tried to spatialize the data, but it became impossible to obtain a temporal survey for such reduced sub-zones of the mudflat. The number of sampling trawls was also very low for each year and the macrobenthos sampling surfaces appear to be insufficient for providing a good estimation of the species richness of the fauna. Many species have densities that fluctuate between 0 and a low value. In fact, for some benthic species, the estimated densities are so low that it would be necessary to increase the sampling surfaces considerably in order to correctly measure this parameter. For the benthic compartment, it would probably be necessary to adopt a 500 µm mesh size for sediment sieving to correctly estimate the densities dominated by small species, such as *Manayunkia aestuarina* and *Tubificidae*. However, this mesh size was available only in 1980. Clearly, for the future, sampling strategies must be re-examined, and a true monitoring program involving trawling should be planned to correctly estimate fish abundances and fish pressure on benthic prey.

Given that fish and birds are mobile organisms, it is undoubtedly necessary to integrate elements that are external to the mudflat in order to estimate the minimum mudflat surface that needs to be preserved. For example, fish feed in other habitats, particularly in the rich subtidal *Abra alba - Pectinaria koreni* fine sand community located in the eastern part of the Bay of Seine (Dauvin & Desroy, 2005). The youngest individuals (G0) feed preferentially on meiofauna; this is certainly true for the common sole *Solea solea*, which consumes harparcticoid copepods (Amara & Bodin, 1995). The meiobenthic compartment could constitute a key element of the North mudflat ecosystem, but there is no data about its evolution over the last three decades. On the other hand, the birds that depend trophically on the North mudflat are the most sensitive to its surface reduction. Not only does this reduction deprive them of a food source, but it also deprives them of a resting place. The ornithological data do not pose the same kinds of problems as the benthic and fish data since measurements are taken regularly, using the same methodology over the time. Nonetheless, for this type of data, it is difficult to get an idea of the possible variability in the results due to the counting methods, which have a certain percentage of relative uncertainty that, in theory, is constant over time.

Conclusions

Simultaneous observations of benthic fauna, ichtyofauna, avifauna and estimates of the limits and surface of the North mudflat exist for only a few periods. It is clear that the North mudflat, downstream from the Normandy Bridge, has regressed over the last three decades. Three bird species (the avocet, the Eurasian curlew and the common shelduck) among the seven studied also show clear decreases over time; these reductions seem to be correlated with the reduction of mudflat surface. No significant relationship between the abundances of these bird species and the benthic biomass has been established. Though trophic capacity probably plays a role in the reduced abundance of these birds, the available benthic data do not allow this role to be characterized. In addition, it is not possible today to distinguish between natural variations and variations with anthropogenic origins. No simple relationship has been found between the benthos and avifauna and the benthos and ichtyofauna, but both these types of fauna exploit the benthos and are probably competing for the space and food available. There seems to be enough benthic biomass to support this food pressure, but to clearly estimate the flux between the benthos as prey and fish and birds as predators would certainly require a more detailed evaluation. In the future, regular and simultaneous sampling of all these compartments with adapted and standardized protocols will be essential to quantify the role played by each.

The approach used is voluntarily pragmatic. But since the ecosystem of the North mudflat is probably connected to other habitats, it will definitely be necessary to have more information about the sediment type and benthic community composition in order to compartmentalize the results spatially. Some processes (e.g., successive re-suspension or silting) that affect either the whole mudflat or just local zones may have a determinant role in the recruitment and survival of benthic fauna as well in the quantification of benthic carrying capacities.

Due to the quantity and quality of the data, the approach used in this study appears limited, especially for estimating the mudflat surface that needs to be restored in order to re-establish the carrying capacity observed at the beginning of the 1980s. For the three birds showing a clear decrease in abundance, a total of 530 ha of mudflat correspond to abundances that are approximately the double of those observed today in Seine estuary. Thus, about 200 ha need to be restored to re-establish the receiving surface for these birds in the future. This will be a challenge given the new constructions planned for the lower part of the Seine estuary, such as new dikes in the Le Havre harbour or a new bridge downstream from the Normandy Bridge.

The North mudflat will disappear completely downstream from the Normandy Bridge if nothing is done to safeguard it. This disappearance will entail the loss of the estuarine functions that depend on the mudflat, such as the nursery for certain fish species and the zone of reception for certain bird species. Furthermore, in the future, it will be necessary to determine whether or not the other mudflat zones—those recreated upstream of the Normandy Bridge as Port 2000 compensatory measures and those established naturally along the northern dam downstream from the Normandy Bridge—will play the same trophic role as the North mudflat.

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