Chapter 4

Ecological goals and associated habitat needs for fish in estuaries: a case study of the Zeeschelde (Belgium)

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Abstract

We describe habitat needs for fish populations in estuaries needed to ensure the realisation of ecological goals. We take the view that Good Ecological Status (GES), as defined by the European Union Water Framework Directive (2000/60/EEC), is obtained when those ecological goals are fulfilled. The Zeeschelde estuary is presented as a case study for the description of ecological goals, but the described approach can be applied to all North Sea estuaries. In order to make the method widely applicable we first classify fishes into guilds, relevant for the formulation of ecological goals. Next we describe guild-specific ecological goals for fish. Based on the literature, habitat requirements for specific fishes are defined and used to define habitat needs allowing a proper functioning of the estuarine ecosystem. We describe habitat needs at a guild level and indicate how these can be achieved.

Keywords: ecological goals, estuaries, fish, habitat needs, Zeeschelde

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1 Introduction

The progressive loss of estuarine areas remains a serious threat to the preservation of estuarine biotopes and the integrity of estuaries as a whole. In particular, the historical loss of intertidal areas is obvious and the associated effects are disproportionally large (Elliott & Taylor, 1989a; McLusky et al., 1992; Costanza et al., 1997). Davidson et al. (1991) referred to the process of gradual loss of shallow habitats as the “estuarine squeeze”. In the upper part i.e. the freshwater tidal zone, the “estuarine squeeze” has moved the high water line shoreward through land claim, building of sea defences and dock construction. The driving forces of the lower part of the “estuarine squeeze” are the extraction of sediments, the construction of barrages and sea level rise. The combined effect of these hydromorphological pressures has resulted in the loss of intertidal areas, the relative increase of deeper subtidal areas and the narrowing of the estuarine channel (Van den Bergh et al., 2009). A comparative analysis of 14 European estuaries showed that land claim, channel management, barrages and impoundments are the most important mechanisms resulting in disturbances of the estuarine fish communities (Cattrijsse et al., 2002). These range from a loss of species diversity, through a change from an estuarine to a freshwater assemblage, to the disappearance of whole communities. Under natural conditions, erosion and sedimentation are in balance and the natural loss of a habitat at one site may be compensated by sedimentation at another site (McLusky & Elliott, 2004). Even floods or storm-surges that may destroy complete habitats are likely to be remediated in natural systems by a resulting adjustment development of the main tidal channels. Due to these natural changes in hydrogeomorphology fish communities will slowly change to a species composition more suited to the new situation. Where land claim or dredging negatively affect benthic communities, a principal food resource for estuarine fishes, those fish communities will also be affected in terms of species number, abundance and biomass (Elliott et al., 1998; Kennish, 2002). Reduction of the food supply and the loss of habitat reduce the value of estuaries as a nursery area and thus its carrying capacity (Thiel, 1995; Köhler & Köpcke, 1996; Drake & Arias, 1997; Colclough et al., 2005; Lotze et al., 2006; Martinho et al., 2007). The presence of ports, dykes and other artificial structures that stabilize the channel create an increased flushing effect and segregation of the tidal currents (Cattrijsse et al., 2002). The building of docks, wharves and jetties result in a loss of intertidal area or soft sediment, although they may create an artificial hard substratum which attracts a rocky
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To avoid further habitat loss, aquatic ecosystems are protected by binding regulations. The protection of nature, diversity of habitats, species, as well as the functioning of aquatic ecosystems is the subject of a series of international agreements and legal commitments (Apitz et al., 2006). For example, in Europe, environmental legislation that covers estuaries includes the European Water Framework Directive (WFD, 2000) as well as the Wild Birds and Habitats Directives (BHD, 1979, 1992). The first of these directives requires ecological quality goals to be met, whereas the latter directives require conservation goals to be met. Hence, the ecological goals require to be derived against the habitat needs of the ecological components of the system, in this case the fishes within estuaries, and they should not be in conflict with conservation goals. In addition, different competences derive from local, regional, national, multilateral and international initiatives, each with their own objectives and targets. Clearly, these commitments apply on different spatial scales covering from the regional scale (Europe, North Sea area, country) to the local scale (river basin, river, habitats). Consequently, an assessment of compliance to environmental regulations that are in vigor optimally adopts an integrated, hierarchical structure (Fig. 4.1). Under this approach, particular commitments aim at sustainable and integrated management but may focus on a different spatial level of the ecosystem and its functioning. Accordingly, objectives at each level aim at ensuring effective functioning of the ecosystem to achieve the commitments involved. The term ecological emphasizes that these are functional targets within the ecosystem, including interactions among the different fish species and between fish and their environment. Once the objectives are set, quantitative indicators or measurement endpoints have to be defined in order to measure the actual status, and to compare the ecosystem state to reference levels set by the ecological goals (Van den Bergh et al., 2005, 2009). Depending on the scale, indicators are either based on integrated data or represent an explicit measure of the state of the ecosystem. Therefore, any monitoring scheme should provide a wide range of data so that at each level of assessment, the necessary information can be obtained (Detenbeck & Cincotta, 2008). Restoration measures subsequently aim at restoring the processes that generate the required habitats and species populations to comply with the proposed ecological goals (Elliott et al., 2007a). Often the potential for restoration remains possible, since most species and functional groups persist, albeit in greatly reduced numbers (Lotze et al., 2006).
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Figure 4.1: Hierarchical integration of conservation objectives depending on the spatial scale (adapted Van den Bergh et al., 2009).

This study defines ecological goals for estuarine fishes using the Zeeeschelde (tidal Schelde in Flanders, Belgium) as a case study and example for other North-East Atlantic estuaries. Ecological goals for estuarine fishes are defined as targets that should be reached in order to ensure a healthy and dynamic fish community in that ecosystem. As such they contribute to the reestablishment of the estuaries’ autogenic processes, its organisation, vigor and resilience. Van den Bergh et al. (2005) describe qualitative ecological goals for 22 key indicators in the Schelde Estuary in a hierarchical way, starting from physical and chemical processes up to the level of specific habitat types and species. This study develops this approach and describes in detail appropriate ecological goals and habitat needs for specific fish guilds in estuaries in order to assure the ‘good status’ of fish populations as required by the Water Framework Directive. The habitat needs ensure spawning, breeding, feeding or growth to maturity. An estuary is defined as that part of a river which is under tidal influence (Fairbridge, 1980; Elliott & McLusky, 2002). Ecological status can be assessed using classification tools that were especially developed for that purpose. For example, Breine et al. (2007) developed a fish-based estuarine index of biotic integrity (EBI) for the mesohaline and oligohaline zones in the Schelde estuary (Chapter 7). The EBI includes attributes such as total number of fish species, percentage of smelt (Osmerus eperlanus) individuals, percentage of marine migrating juvenile fish and percentage of omnivorous and piscivorous fish. However, it is axiomatic that
fish species of the different ecological guilds which are typically present in an estuary should be able to complete their lifecycles within or adjacent to the estuary (Jager & Kranenbarg, 2004). Hence, the guild approach can be applied to define the habitat needs to meet these ecological goals against a set of anthropogenic pressures such as pollution and morphological change. The implementation of mitigating or compensation measures to those pressures (as per Elliott et al., 2007a) therefore has to ensure the presence of a diversified fish community as stipulated by the WFD. In particular, the EU has stipulated that by 2015 the fish community should be comparable to that of an estuary in a good ecological status or if the water body is heavily modified which is the case for the Schelde, then the water body has to be adjudged as having Good Ecological Potential (2000/60/EEC).

This study develops these concepts by introducing the guild concept as a framework for establishing ecological goals, defining the ecological goals for the Zeeschelde estuary based on knowledge of the frequenting fish guilds and then linking these goals to specific habitat needs of the target fish fauna.

2 The ecological guild concept as a framework for defining ecological goals and habitat needs

The guild approach to categorizing estuarine fishes is used in this chapter as a concept to define goals and habitat needs. A guild or a functional group is a group of species that exploits the same class of environmental resources in a similar way (Coates et al., 2007; Elliott et al., 2007). The guild concept therefore merges biodiversity with the ecosystem functioning, as it links species to the functions or services that estuarine ecosystems are providing to them, such as the provision of food, shelter and habitat. A recent global review of the application of the guild concept to estuarine fish communities indicates that the separation of estuarine fish communities in three groups of functional guilds provides sufficient information for an assessment and that these guilds produce more information regarding the functioning of the estuarine systems than do structural indices such as taxonomic diversity (Elliott et al., 2007; Franco et al., 2008). The groups include the Estuarine Use Functional Group, the Feeding Mode Functional Group and the Reproductive Mode Functional Group. The authors defined within each of these major categories subgroups which will be referred to as guilds. The presence of the different guilds therefore indicates the particular ecological function that the estuarine ecosystem fulfils. In turn, we take the view that the conservation of each guild as an integral part of the estuarine fish community is adopted as an ecological goal such that
achieving each ecological goal is assumed to indicate the good ecological status (or potential) of the estuary. This concept is globally applicable but should be adapted locally using fish sampling data and historical records to narrow down the set of ecological goals and associated habitat needs to only those guilds of the functional groups that should be present in the estuary at good ecological status or potential and, to which management plans need to be addressed. However, this approach is complicated by the fact that few fish species are confined to particular estuarine habitats or to estuaries (Craig & Crowder, 2000; Franco et al., 2008). Often estuarine fish populations connect to regional marine and freshwater populations (Able, 2005). Accordingly, the regional status of fish populations affects the status of those populations at finer spatial scales. Therefore, we consider it necessary to define ecological goals on four spatial scales of interest which are: the regional scale, the river basin scale, the estuary scale and the habitat scale.

3 The Zeeschelde estuary as case study

We apply the concept of ecological goals to the fish community of the Zeeschelde estuary, the Belgian part of the Schelde estuary. The ecological goals for the Zeeschelde and its tributaries under tidal influence are developed based on long term peer reviewed fish sampling data (Van Damme et al., 1994; Maes et al., 1996, 1998a,b; Peeters et al., 1998; Maes et al., 1999; Peeters et al., 1999; Ercken et al., 2002; Maes et al., 2003, 2004a,b, 2005; Stevens, 2006; Stevens et al., 2006; Cuveliers et al., 2007; Buysse et al., 2008 and Guelinckx et al., 2008). This data contributed to the development of a reference list (Chapter 3, Breine et al., 2008: Table D in annex). In this list all fish species were assigned to the ecological guilds defined by Elliott et al. (2007) and Franco et al. (2008). We consider here the GEP reference lists as it is impossible to reach the MEP status. Ecological goals (EG) and habitat needs (HN) for the Estuarine Use Functional Group were then defined (Fig. 4.2) since they comprise those of the feeding mode functional group and the reproductive mode functional group. Indeed if a sustainable population of freshwater and estuarine species is present and marine migrants and diadromous species frequent the estuary one may assume that an undisturbed trophic web is present and that the recruitment occurs normally. The species were assigned to guilds based on an extensive and critical literature review of the life strategies of the fish species combined with expert judgment. This takes into consideration ontogenetic changes, i.e. that fish can occupy different habitats during particular periods of their life history (Bulger et al., 1993;
Elliott & Dewailly, 1995; Schiemer & Waidbacher, 1999; Pihl et al., 2002; Quak, 1994; Elliott & Hemingway, 2002; van Emmerik, 2003).

For the estuarine use functional group, different guilds have been distinguished according to habitat use, which is related to the life history strategy (Elliott & Dewailly, 1995; Mathieson et al., 2000; Pihl et al., 2002; Thiel & Potter, 2001; Franco et al., 2008). For the marine migrants we only consider the marine juvenile migrants since estuaries are considered as essential habitats for this ecological guild.


4 Ecological goals for the estuarine use functional group

Within this group we distinguish four relevant guilds for the estuary: freshwater species, estuarine species, marine migrants and diadromous species. Marine stragglers are not included since they do not depend on the estuary to complete their life cycle (Elliott et al., 2007).

4.1 Freshwater and estuarine species

The presence of freshwater species is restricted to the freshwater, oligohaline and mesohaline parts of the estuary (Franco et al., 2008). However, ecological goals for this guild specifically target the freshwater tidal part of the estuary (Fig. 4.2). For estuarine species estuaries can be regarded as essential habitats for spawning, feeding and growing, situated in the salinity range from the oligohaline to the marine (Franco et al., 2008).
For these guilds the following ecological goals (EG) are suggested:

**EG1**: On a regional and basin-wide scale a sustainable population of all reference freshwater species represented in Table D (Appendix) as well as a sustainable population of estuarine resident species (Table D) should be present.

**EG2**: On an estuary scale seasonal dynamics of the freshwater species and estuarine fish communities should be preserved allowing those species to move to their spawning places, nursery and feeding habitats. A nursery is defined as a habitat that compared with other habitats supports a greater contribution to the adult recruitment (Beck *et al.*, 2001).

**EG3**: On a habitat scale, different life stages of freshwater and estuarine species should be present according to the habitat type.

### 4.2 Marine migrants

Marine migrants were previously defined as marine juvenile species or marine seasonal species and are a dominant guild in European estuaries (Franco *et al.*, 2008; Selleslagh *et al.*, 2009). They share many biological and ecological properties with estuarine species but do not spawn in the estuary. Their presence in the estuary depends on the spawning success offshore. The main difference between the marine migrants and estuarine species guilds is the time spent in the estuary. Two resources are considered of importance: space and food. The former can be subdivided into amount of area used and amount of time this area is used (extent versus duration). Based on the present knowledge of marine migrants, the following ecological goals are suggested:

**EG4**: On a regional and basin-wide scale marine migrants (0-group individuals) should be present in accordance to the season.

**EG5**: Preserving the typical seasonal sequence of marine juvenile migrants allows the full exploitation of the estuary as nursery and feeding ground and is a priority goal.

**EG6**: Young marine individuals should find temporary shelter and food in the different habitats.
4.3 Diadromous fish species

Diadromous fish use both marine and freshwater environments to complete their life cycle (McDowell, 1996). The (sub)tidal transition zone between rivers and oceans is a crucial habitat for diadromous fish linking spawning grounds with adult habitat. Some anadromous fish species, for instance twaite shad (*Alosa fallax*), move upstream and use the tidal freshwater area as spawning habitat (Maes *et al.*, 2008). Shallow areas or vegetated habitats throughout the estuary serve as essential nurseries for 0-group anadromous and catadromous fish. Based on the present knowledge of diadromous species, the following ecological goals are suggested:

**EG7**: On a regional scale, endangered diadromous populations of in particular Atlantic salmon (*Salmo salar*), Atlantic sturgeon (*Acipenser sturio*), houting (*Coregonus oxyrhynchus*), allis shad (*Alosa alosa*) and European eel (*Anguilla anguilla*) (Robinet & Feunteun, 2002; ICES, 2006) should have self sustaining populations.

**EG8**: Basin-wide, self sustaining populations of geographically-relevant diadromous species (e.g. twaite shad (*Alosa fallax*), river lamprey (*Lampetra fluviatilis*), smelt (*Osmerus eperlanus*), thinlip mullet (*Liza ramada*) and flounder (*Platichthys flesus*) for the Schelde) should frequent the estuary.

**EG9**: Within the estuary and at a habitat level diadromous individuals from the > 0-group should be present.

5 Associated habitat needs for the estuarine use functional group

Estuarine species spawn only in estuaries where they complete their life cycle although they can show regular movements between the estuary and adjacent aquatic habitats (Franco *et al.*, 2008). Marine migrants are defined as those species that use estuaries as a nursery area as 0-group individuals and shallow areas in the marine and brackish part of estuaries that are either turbid or vegetated may especially qualify as fish nurseries (Le Pape *et al.*, 2007; Lazzari, 2008). Rijnsdorp *et al.* (1992) and Gibson (1994) hypothesize the relationship between nursery size and fish recruitment which indicates that increasing total estuarine fish nursery habitat has a positive effect on the recruitment of marine juveniles and can act as a rehabilitation measure. Estuaries are characterised by seasonal patterns in species composition that are related to species-specific life history strategies and are highly influenced by
processes occurring in the sea. Complete seasonal niche partitioning of the particular estuarine ecosystems suggests optimal functioning of the fish nurseries.

The freshwater tidal area of the Schelde, including its tributaries, is dominated by representatives of eurytopic fishes, i.e. fishes that are able to tolerate a wide range of conditions and have consequently very widespread distributions (Calow, 1998). They include roach (*Rutilus rutilus*), pike (*Esox lucius*), perch (*Perca fluviatilis*) and bream (*Abramis brama*) (Chapter 2). This is the result of a lowland setting and a river system that is categorised as the bream zone (Huet, 1949). Eurytopic fish benefit from a good hydrological connection between the different components that together constitute the river corridor (channel, marshes, floodplain) and from the presence of tributaries (Pollux *et al*., 2006). Although habitat preferences often change during the course of development (Grenouillet *et al*., 2000) supratidal floodplains are considered essential habitats as they provide suitable spawning and juvenile conditions e.g. as a food source (Tockner *et al*., 2000).

Rheophilic species have all their life stages confined to lotic waters (Nobel *et al*., 2007). Rheophilic A species have a life strategy adapted to fast water and prefer the mid-channel of large rivers such as the Schelde (e.g. dace, *Leuciscus leuciscus*, Van Liefferinge *et al*., 2004). Some stages of the life history of rheophilic B species (e.g. gudgeon, *Gobio gobio* and burbot, *Lota lota*) are confined to well connected backwaters (Aarts & Nienhuis, 2005). Rheophilic B species are absent from the main channel, as these habitats are replaced by intertidal marshes although they should also occur in the tributaries.

Limnophylic species may occur but estuarine habitats are not essential. Based on habitat preferences, efforts should focus on rheophilic A and B species as well as eurytopic fishes. Based on present knowledge the following habitat needs (HN) are suggested:

**5.1 Regional and basin-wide scale habitat needs: connectivity**

**HNI:** On a regional scale fishing activities should be controlled in order to protect marine migrants and diadromous species.

Illegal fishing is one of the greatest threats to marine ecosystems (FAO, 2005). The depletion of key fish stocks can be stopped by adopting the MCG scenario (monitoring, control and surveillance) involving prevention and deterrence. The creation of marine reserves assuring protection against fishing or development is essential. If 25% of the North Sea surface would
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be fishery free the number of fish species present would double and its biomass would increase with 200% (Dekker et al., 2009).

HN2: On a basin-wide scale, the ecological connectivity along longitudinal and transversal river gradients permits marine migrants to enter the estuary and the development of a sustainable fresh water population of rheophilic A and eurytopic fish species in the estuary.

Ecological connectivity permits unconstrained movements of diadromous fish between spawning and nursery grounds and the adult habitats (Lassalle et al., 2009). This includes the access to inland water systems and catchment areas which have to be (made) passable for migrating fish, even those with restricted swimming capacity, such as glass eel and three-spined stickleback (*Gasterosteus aculeatus*) or those as flounder larvae which rely on selective tidal stream transport for migration (Jager, 1999). Tributaries should be accessible since they contribute to the recruitment of migrant species (Pollux et al., 2006). This ecological connectivity includes an absence of physical barriers or mitigation by specialised constructions to allow fish passage. It also includes the absence of chemical barriers by ensuring a good water quality (e.g. dissolved oxygen concentration, Chapter 5) and low nitrate concentration (Tong, 2001). As an example, table 4.1 shows DO standards developed by the Thames Tideway Strategy Group (TTSG) aimed specifically at the Thames Estuary Tideway, but which have a more general application in other British transitional waters (Turnpenny et al., 2006).

Table 4.1: Dissolved oxygen (DO) standards proposed by the Thames Tideway Strategy Group (Turnpenny et al., 2006)

<table>
<thead>
<tr>
<th>DO (mg l(^{-1}))</th>
<th>Return Period (yrRP, years)</th>
<th>Duration (# of 6 hour tides)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>1.5</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note: the objectives apply to any continuous length of river ≥ 3 km.*

*Duration means that the DO must not fall below the limit for the stated number of tides.*

*A tide is a single ebb or flood.*

The bases for these standards are:

- The one week standard (4 mg l\(^{-1}\), 1 yrRP, >29 tides) was selected to ensure protection against chronic effects such as depression of growth and avoidance of hypoxic areas.
- The 24 h standard (3 mg l\(^{-1}\), 3 yrRP, >3 tides) and the 6 h standard (2 mg l\(^{-1}\), 5 yrRP, > 1 tide) were selected to provide protection to stocks.

- The lowest standard (1.5 mg l\(^{-1}\)) was included to ensure protection from mass mortalities.

However, in chapter 5 we use a modelling approach to set specific threshold values for DO in the Zeeschelde.

5.2 Estuary scale: space

HN3: The estuarine nursery size should be sufficiently large (temporal and spatial) such that it contributes significantly to the recruitment of young estuarine and marine fish populations.

The importance of estuaries for recruitment of marine species decreases upstream along the decreasing salinity gradient (Elliott et al., 1990). Within a geographic area the estuary should have an undisturbed hydrographic regime assuring the presence of nursery areas such as salt and freshwater marshes with a diversified creek pattern (Rozas et al., 1988; Hampel et al., 2003, 2004). As such intraspecific and interspecific competition is prevented by abundant food resources and by the spatial and temporal segregation within the nursery areas (Martinho et al., 2007). Size is only one criterion, the estuary should also have an appropriate water depth and its shape should be convenient for the larvae (hydrodynamic and climatic regime). Connectivity and favourable hydrodynamic conditions (tidal transport) should allow the larvae to move to adult habitats and the physical-chemical conditions (e.g. DO, salinity, suspended matter) should not be restrictive.

HN4: At the scale of the estuary, the presence of floodplains and side waters along the tidal freshwater part of the estuary ensures the annual recruitment of freshwater eurytopic fishes.

This habitat need relates to the hypothesis that floodplains and side waters represent a critical factor in life history of eurytopic fishes through the provision of refuge and food resources (Grandmottet, 1983; Turner et al., 1994; Sindilariu et al., 2006). Pas et al. (1998) state that Tielrodebroek, a flood control area of about 90 ha at the mouth of the River Durme, functions as a spawning and nursery area for some freshwater species. The presence of the experimental flood control area under the influence of a controlled reduced tide (FCA-CRT) in Lippenbroek, situated in the freshwater zone of the Schelde estuary, has shown its potential as nursery and refuge area for freshwater and some diadromous species (Simoen et al., 2007). The presence of fish larvae of species such as Prussian carp (Carrasius gibelio), stone moroko
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(Pseudorasbora parva) and three-spined stickleback (Gasterosteus aculeatus) indicate that spawning activities occur in Lippenbroek. Channel geometry in natural watersheds is typically meandering with a diversity of substrata (Karr & Dudley, 1981).

5.3 Habitat scale: diversity and quality

HN5: The presence of shallow, low dynamic (as opposed to high tidal energetic areas) habitats (e.g. sheltered mudflats, saltmarshes and tidal marshes with permanent pools) that provide protection and a high and continuous supply of food should be ensured for estuarine species and marine juvenile migrants (Amara et al., 2001; Le Pape et al., 2003; Gilliers et al., 2006).

A range of different site substrata should be present to contribute to the benthic primary production (Svensson et al., 2007). Although fish in estuaries are in general opportunistic (Miller & Dunn, 1980; Elliott et al., 2002; Breine et al., 2007), feeding interactions assessments reveal the existence of different diet compositions in species (Salgado et al., 2004; Dauvin & Desroy, 2005; Dolganova et al., 2008; Pasquaud et al., 2008). It may be assumed that the abundance and distribution of fish feeding in the estuary, and hence the carrying capacity for fishes, is related to the quantity of food available in the intertidal and subtidal areas (Able et al., 2005). In turn hydrographic regime, site specificity and substratum are also factors controlling fish feeding (Elliott et al., 2002). Although generally small in surface, tidal mudflats are well defined as juvenile fish feeding areas (Costa & Elliott, 1991; Amara & Paul; 2003; Stevens, 2006). For estuarine species a diversity of habitats (mudflats, marshes, creeks) may lead to higher species diversity (Elliott & Hemingway, 2002). Estuarine residents often produce demersal eggs or have parental care since pelagic eggs and larvae cannot withstand the local currents and wash-out events. For example, smelt will produce its eggs in areas less liable to wash-out, ensuring its young are retained in the estuary (Kottelat, 1997; Kottelat & Freyhof, 2007) and other species migrate into the intertidal to spawn during high water levels (Edwards & Steele, 1968; Van der Veer & Bergmann, 1987). The benefits of intertidal spawning follow from the fast development rate when emerged (Taylor, 1999), due to the food availability and from temporal and spatial refuge for adult spawners and embryos (Gibson, 1982; Van der Veer & Witte, 1993). Creeks are juvenile habitat for many species (Chapter 6; Nemerson & Able, 2004) and hydrology and channel morphology influence the occurrence of nekton in tidal marsh creeks (McIvor & Rozas, 1996). The presence of tidal marshes additionally provides shelter and food for a large variety of fish.
species. While many larvae behave as habitat generalists, shelter and associated food availability will remain important. Sheltered microhabitats (e.g. tidepools) provide refuge from predators or competitive species (Kneib, 1987). Therefore the characteristics of mudflats and tidal marshes should be defined according to their good quality as well as their dimensions, allowing the development of a dynamic and diversified habitat. The mudflats should have an optimal sediment composition and position in the tidal frame for the maintenance of suitable prey biomass (McLusky & Elliott, 2004).

Environmental variation upstream and in the tidal tributaries will result in different species having successful recruitment at different times, a feature important for coexistence and satisfying specific demands. For eurytopic and rheophilic species the availability of sheltered diversified intertidal habitat surfaces and subtidal areas, with a diverse food supply in the freshwater estuary, are essential as nursery and feeding grounds (Karr & Dudley, 1981; Angermeier & Schlosser, 1987; Laffaille et al., 2004). In turn, microhabitats with low water velocities e.g. side-arms and flood zones, are essential especially for fish larvae. Varying flow regimes result in substratum sorting, erosion and deposition events which may influence the production of ecological niches and thus species diversity (Karr & Dudley, 1981). Mann (1996) gives an overview of the critical and preferred current velocities for fish larvae. Upstream, the physical conditions of the tributaries are supposed to be less severe than in the main channel, allowing the presence of macrophytes which increases the habitat structural complexity. This favours the survival of rheophilic B offspring since it provides shelter and food. In addition limnophilic species can benefit from the presence of plants. The presence of upstream situated spawning habitats such as sand beds, habitats with gravel and/or stone bottom with clear and oxygenated water and sufficient intertidal habitat are therefore required for the success of the rehabilitation programmes of diadromous populations. The interaction of temperature, surface area, stream flow and productivity influences the presence of diadromous species (Béguer et al., 2007) and an appropriate morphology should be present to provide shelter and food for >0-group diadromous individuals. Banks should contain varying stretches to enhance recruitment e.g. stretches with a mixture of pebbles, flooded grass, aquatic plants and tree roots. Dredging activities should not occur and mud should be absent so that spawning can occur on gravel or sand. The eggs and larvae should not be smothered by layers of fluid mud.

HN6: A good water quality is an essential requirement for fish (Huet, 1962; Mann, 1996).
For example, long term low dissolved oxygen reduces reproduction and migration particularly in a spring and summer spawning species (Landrey et al., 2007). Seasonal migrations of estuarine species and marine migrants can only occur if conditions in the estuary are favourable for the fish i.e. temperature (Aprahamian, 1988) and dissolved oxygen conditions should be within acceptable ranges. For example temperatures above 15°C and DO below 5 mgl\(^{-1}\) can produce a water quality barrier to migration (Elliott & Hemingway, 2002; Maes et al., 2007, 2008). DO should be high enough that it does not create constraints for the larvae and juveniles (see HN2) since they are less successful at leaving or avoiding regions with low DO concentrations (Breitburg et al., 1999). Maes et al. (2007) state a threshold of 5 mgl\(^{-1}\) as the DO minimum based on criteria for US estuaries, as outlined by USEPA, and on empirical models describing the response of estuarine fish to different oxygen concentrations (Maes et al., 2005, 2007, 2008). Pollutants (heavy metals and organic contaminants) have a negative impact on fish growth and density (Eastwood & Couture, 2002; Forester et al., 2003; Gilliers et al., 2006) and diversity (Courrat et al., 2009). Searcy et al. (2007) suggested a relation between a higher mortality and a slower larval and juvenile growth and hence pollution should be avoided.

As a summary figure 4.2 groups the different ecological goals and associated habitat needs.
**Figure 4.2 Ecological goals and associated habitat needs in the Schelde estuary.**

Ellipses include the ecological goals and rectangles the associated habitat needs and the arrows indicate migration direction. MM: marine migrants, AS: anadromous species, CS: catadromous species, ES: estuarine species, FS: freshwater species, DO: dissolved oxygen, FCA: flood control area

### 6 Rehabilitation processes in the Zeeschelde

The primary goal for the rehabilitation of the Zeeschelde is to re-establish the estuary’s autogenic processes (Van den Bergh *et al.*, 2005). These authors focused on the ecological rehabilitation of the estuary whereby measures were defined for different zones. We link the proposed measures with the habitat needs defined for fish.

**Adding space improves connectivity and habitat diversity**

The preferred alternative to the updated Sigmoplan (see introduction) couples ecological rehabilitation and sustainable nature with flood control measures and navigation requisites (Couderé *et al.*, 2005). This plan should be executed by the year 2030. It includes the creation of 1400 ha tidal wetland through managed realignment, 1100 ha tidal wetland under reduced controlled tide in flood control areas (FCA-CRT) 1500 ha of ‘winter bed’ for the upper...
reaches and 2000 ha of non tidal wetlands, 1000 of which in flood control areas (FCA-Wetland) (Fig. 4.3, Table 4.2).

Figure 4.3: Ecological restoration measures for the preferred alternative to the updated Sigma plan.

Table 4.2 Ecological rehabilitation measures relative for fish in the Zeeschelde.

<table>
<thead>
<tr>
<th>Zone</th>
<th>rehabilitation</th>
<th>surface (ha)</th>
</tr>
</thead>
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<tr>
<td>mesohaline</td>
<td>connection</td>
<td>83</td>
</tr>
<tr>
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<td>realignment</td>
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</tr>
<tr>
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<td>realignment</td>
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</tr>
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<td>FCA-wetland</td>
<td>187</td>
</tr>
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<td>FCA-CTR</td>
<td>577</td>
</tr>
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<td>realignment</td>
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</tr>
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<td>wetland</td>
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Realignment will create dynamic estuarine habitats. In chapter 6 we record the use of mudflats and tidal marshes by juvenile species. The presence of rivulets on the mudflats, the position of the marsh creeks in the tidal frame and the dimension are important characteristics that enhance the use by fish. In addition presence of permanent pools will increase the nursery function of the creeks.

Flood control areas (FCA) constitute extra storage capacity for water during storm surges during which fish from the Zeeschelde enters the floodplain. Pas et al. (1998) showed that Tielrodebroek, a flood control area of about 90 ha at the mouth of the River Durme, functions as a spawning and nursery area for some freshwater species that remain in the brooks. These areas are now subject to agricultural activities which can have a negative effect on the fish. The creation of a natural wetland (FCA-wetland) with permanent pools will reduce impacts from fertilisers and pesticides and enhance nutrient cycling and water retention, which in turn will increase the carrying capacity of the floodplain. Research is needed to optimise the connectivity between the floodplain and the river.

A flood control area under the influence of a controlled reduced tide (FCA-CRT) creates marshes that are less dynamic than those along the river. The realisation of creeks and permanent shallow pools constitutes an ideal spawning and nursery habitat for many fish species. Here again extra research is needed to optimise the exchange possibilities between the floodplain and the estuary.

Winter beds are for freshwater species in tributaries an essential spawning and nursery habitat. Grift (2001) observed that fish rapidly colonized newly created floodplain water bodies in the river Rhine.

Reconnected oxbow lakes have a beneficial value for the riverine fish community, since they provide a habitat that is better suitable for 0-group fish than the main stream. In addition they form important spawning and nursing areas for rheophilic species. Restoring the interaction between the river and abandoned river meanders (Oude Durme, Oude Schelde) is to be considered as beneficial for rheophilic species.

The creation of shallow tidal areas in the mesohaline zone improves oxygenation since they positively influence the surface-to-volume area (Chapter 5). Intertidal, shallow habitats are essential to reinstate physical and chemical processes and hence increase the estuary’s self-purification and filtering capacity that sustains water quality (Van den Bergh et al., 2005;
Lotze et al., 2006). The creation of space will reduce the current velocity and the associated effects such as erosion and turbidity and will as such also increase intertidal habitat surface. Brys et al. (2005) and Van Braeckel et al. (2006) suggest that the only sustainable way to protect tidal marshes against destructive erosion is by facilitating the creation of mudflats combined with shallow zones, although new marshes can only be created taking into consideration appropriate geomorphological conditions (Van Braeckel et al., 2006).

In addition by increasing the surface the carrying capacity of the estuary is enhanced. Indeed in chapter 2 we report a high abundance of marine migrants such as herring, seabass, estuarine species (Gobiidae) and diadromous fish in the mesohaline zone. Juveniles are recorded in the tidal marshes seeking shelter and food (Chapter 6). At present the tidal marshes in the mesohaline zone are not used as nurseries because there are too few permanent pools. It is therefore essential that the realignment creates areas that are permanently flooded so that these can function as a spawning place for estuarine species and as a nursery for marine migrants and diadromous species. In chapter 6 we suggest as well the importance of rivulets on the mudflats and the position of the marshes and creeks in the tidal frame for foraging fish.

Connecting pools (83 ha) will only be beneficial for fish if these can return to the main river. Research is needed to investigate the passage of marine and estuarine species through culverts.

Since 2007 species richness and fish abundance have increased in the oligohaline zone. We recorded the presence of mainly freshwater species but also diadromous, estuarine and marine species (Chapter 2). Tidal marshes in this zone are visited by juvenile freshwater and diadromous species such as eel and flounder (Chapter 6). The creation of wetland (187 ha) and estuarine nature (620 ha) will be mainly used by freshwater species and diadromous species if they can enter the wetland and flood control areas (FCA). Again care should be taken that the wetland has permanent flooded areas and that fish can occasionally migrate between the main river and the wetland. This can be done by installing tidal flap gates. However, research is needed to define optimal gate constructions. The installation of tidal flap gates in Tielrodebroek will increase its carrying capacity. In the Durme the realignment of the Bunt will also be a gain for fish. Care should also be taken for the elevation so that the created tidal mudflats and marshes can be used in an optimal way by freshwater species as spawning, nursery and feeding places and by occasionally visiting estuarine species as resting and feeding places.
Freshwater species are abundant in the freshwater zone. We recorded diadromous and occasionally estuarine species as well as marine migrants (Chapter 2). The tidal marshes are used as juvenile habitat for freshwater species and diadromous species such as flounder and eel (Chapter 6). Due to their elevation in the tidal frame and the presence of only a few permanent pools, the nursery function is not assured. As already mentioned, the realisation of an experimental FCA-CRT such as Lippenbroek in the freshwater zone, proved to be beneficial for fish since it can be incorporated as nursery and spawning places, provide shelter and resting areas and act as feeding grounds (Fig. 4.3) (Simoens et al., 2007). Diadromous species such as flounder (semi-catadromous) also use the Lippenbroek as a nursery. We observed that fish entered via the outlet rather than using the inlet sluices (unpublished results). Rheophilic B species benefit from this connected flood area, e.g. in 2008 we caught one burbot (Lota lota) in Lippenbroek (unpublished data). Occasionally marine migrants and estuarine species were caught in Lippenbroek or in the adjacent river. More research is needed to enhance or facilitate fish passage through the tidal flap gates. These results indicate that the creation of attainable wetlands (1292 ha) and estuarine nature (471 ha) will be beneficial for freshwater and diadromous fish, as well as for occasional estuarine and marine migrants. For the realisation of the latter habitat one must again take into account the elevation of marshes in the tidal frame.

Physical and chemical barriers preventing migration of diadromous species should be removed or bypassed (Stevens et al., 2009). Solving fish migration problems may not primarily depend on an engineered fish passage, but rather on natural solutions such as restoration of old meanders or the creation of a nature-like bypass channels. This will avoid change of substrate which can have an effect on habitat availability of certain species (Mouton et al., 2007). The basic steps to create adequate fish passages in lowlands are explained comprehensively by Kroes et al. (2006).

To avoid strong riverine peak discharges, retention areas upstream should be created, e.g. through dike relocations. Such restoration practices are planned in the Nete basin a tidal tributary creating about 1347 ha of floodplain (Fig. 4.3). Upstream river rehabilitation and mitigation measures will improve the lateral connectivity of main channels to an ecotone complexity beneficial for fish (Angermeier & Karr, 1983; Sindilariu et al., 2006). In this tributary Habitats Directive annex species such as bitterling (Rhodeus sericeus), burbot (Lota lota) and weatherfish (Misgurnus fossilis), as well as other freshwater and diadromous
species, are recorded and will use the wetland as spawning, nursery and feeding area. The realisation of estuarine nature and wetlands in the other tributaries (Zenne and Dijle) will be beneficial for rheophilic B species.

It is important that all planned rehabilitation measures are realised in order to create sufficient diverse habitat for the fish communities in the Zeeschelde. In this phase separate plans are under environmental impact assessment (EIA). The risk exists that they will all be subject to “minor changes” so that the total picture will no longer fit. It is essential that monitoring programmes should be planned and executed in order to assess the impact of the effectuated rehabilitation actions and to define the carrying capacity of the created habitats.

7 Concluding remarks

Essential habitat requirements for estuarine fish species at three guild levels, as defined by Franco et al. (2008), have been defined. Some of the described ecological goals are applicable in different guilds. If the proposed ecological goals are achieved then different species representing different links within the trophic chain will be present resulting in an undisturbed and complete trophic web as it will also assure an undisturbed reproductive mode functional group.

The proposed ecological goals are only qualitative and therefore further research is needed to provide (semi-)quantitative ecological goals. In addition, the carrying capacity of each habitat type within the different estuary zones should be calculated and mechanisms presented for the recovery of the system (extended as the DPSIRR approach, Drivers, Pressures, State, Impact, Response and Recovery; Elliott et al., 2007a) in order to protect and maintain a good carrying capacity. Finally a fish-based evaluation system should be developed to assess the status of an estuary and to evaluate the impact of the implementation of mitigating measures (Chapters 7 and 8).

In conclusion, it is emphasised that a management structure is required which recognises the ecological goals of organisms, such as fishes, and then links those to the management responses needed to protect and maintain (and where necessary restore) an estuarine system, and those parts of its catchment and marine area, required by fishes in order to complete their life cycle.
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