

Water bird communities in the Lower Zeeschelde: long-term changes near an expanding harbour

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Abstract

The Schelde estuary is an important wintering area and stop-over place for waders and waterfowl using the East Atlantic fly-way. The port of Antwerp is situated in the Lower Zeeschelde, the transition area between the brackish- and freshwater tidal part. Three intertidal areas in this zone (Groot Buitenschoor, Galgenschoor and Schor Ouden Doel) are protected under several international and national legislations. In this study long-term datasets (1982–1998) on water birds in these intertidal areas were analysed and attempts were made to assess the impact of two container terminals, constructed during the covered period. Overall abundance of water birds in the study area did not show any significant trends. Looking at individual areas, maxima and winter means on the Galgenschoor and Groot Buitenschoor were very variable but the peak seasons levelled out with time. On the Schor Ouden Doel, where hunting was banned, maximal numbers increased by a factor of four between 1985 and 1990, mainly due to an increase in Greylag Goose numbers. The trophic composition of the bird populations showed major shifts. Initially, species compositions in winter differed considerably between the three areas, but they became more similar during the study period. The results suggest that the area became more important as wintering and resting place for herbivores such as Greylag Goose and Wigeon while its function as feeding ground and stop-over site for migrating benthivorous birds became relatively less important, especially on the right bank. The water bird populations in the study area varied greatly with the geographic and regional trends for the different species and were influenced by winter severity but no direct proof of impacts from the container terminals could be established. Nearly every season the international 1% level was exceeded by one or more species, but the species of international importance changed with time. National and international protection measures are valuable but insufficient tools for the conservation of these estuarine habitats. A more comprehensive conservation strategy is proposed.

Introduction

Estuaries, defined as parts of a river under tidal influence (Fairbridge, 1980; McLusky, 1993), are important contributors to the world's biodiversity and are cited among the world's most productive ecosystems. However, estuarine environments are

severely threatened. Despite their ecological importance and relative scarcity on a global level, covering less than 0.01% of the earth surface, they suffered large losses because of their multiple socio-economic functions (Davidson et al., 1991; Suchanek, 1994; Gray, 1997; McLusky, 1999). Downstream they provide ideal settlement places

for harbours, industries and towns and the fertile upstream parts are often claimed for agriculture. Drainage of the industrial, domestic and agricultural wastes puts the remaining parts under a heavy pressure and what is left of the biological productivity (e.g. shellfish and fish) is seldom harvested in a sustainable way (McLusky et al., 1992; Heip & Herman, 1995). Waders and waterfowl depend on estuarine production; for many species estuaries are of vital importance as wintering area or as stop-over place during migration and the increasing loss and degradation of these habitats might put some of the species at risk (Meyers, 1990, 1993; Moser et al., 1993, 1995; Goss-Custard et al., 1997).

In the past few decades the alarming declines of regional and global biodiversities, following fragmentation and degradation of typical habitats, have led to the ratification and implementation of several national and international protection laws, directives and conventions in an attempt to stop these negative evolutions and to protect what is left. For wetlands in general water birds are an interesting group to select priority areas for protection and to evaluate the efficiency of implemented protection measures. Situated high in the food web they are likely to react to deteriorations and/or human interventions in the ecosystem. Moreover they are subject to a great public interest (Kushlan, 1993; Moser et al., 1993; Scott & Rose,

1996). Hence, the protection of water birds is an important objective in international conservation measures such as the Ramsar Convention and the European Birds and Habitats directives.

The Schelde estuary, one of the last whole gradient estuaries in Europe, is an important wintering area and stop-over place for waders and waterfowl using the East Atlantic fly-way (Smit & Piersma, 1989). Ysebaert et al. (2000) analysed the zonation of non-breeding water bird populations along its complete salinity gradient. However, long term developments have not been reported on yet in literature. In this paper long term trends in the water bird communities of a short section i.e., the estuarine transition zone between the brackish- and freshwater tidal part, are analysed. The port of Antwerp, number two in Europe for container traffic, is situated in this area, where expanding harbour activities have led to a series of land-claims from the intertidal habitats, threatening to interrupt the estuarine gradient. Since the seventies some measures were taken to secure the ecological value of the remaining tidal marshes and mudflats in the harbour area. Three parts were designated as nature reserves of international importance: Groot Buitenschoor and Galgenschoor on the right bank and Schor Ouden Doel on the left bank (Fig. 1). They are protected under the Ramsar convention, the EU

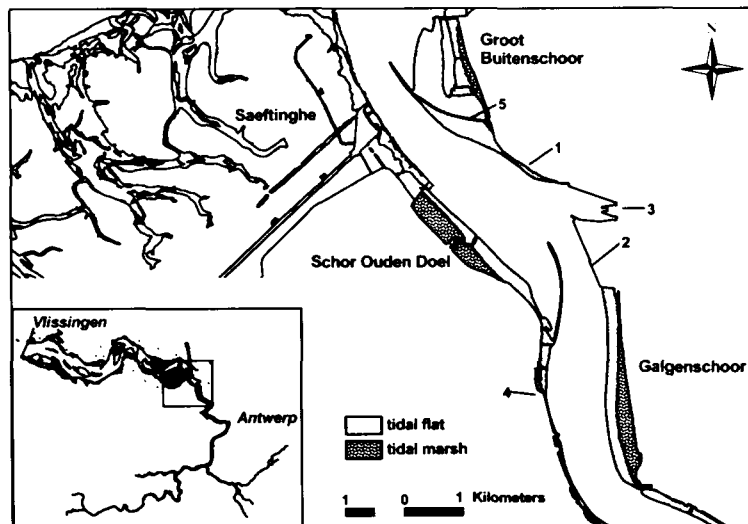


Figure 1. Galgenschoor, Groot Buitenschoor and Schor Ouden Doel situated in the Schelde estuary (1: Northsea containerterminal; 2: Europe containerterminal; 3 Berendrecht and Zandvliet sluices; 4 Doel nuclear powerstation).

Birds Directive (79/409/EEC), several national and regional laws and decrees and they were also proposed to be part of the Natura 2000 network under the Habitats Directive (92/43/EEC) (Van Vessem & Kuijken, 1986; Anselin & Kuijken, 1995). However, due to the ever increasing demands for the international container traffic all these protective measures could not prevent the construction of the Europe container terminal on part of the Galgenschuur (1987–1990), the Northsea container terminal near the Groot Buitenschuur (1994–1996) and a third terminal in a tidal dock near the Schor Ouden Doel (now under construction).

Results from different water bird monitoring programs between 1982 and 1998 are used to assess possible impacts of these engineering projects on the affected estuarine areas of international importance. Long-term changes in abundance, community structure and ecological functions for water birds in the three areas are studied and commented on with respect to local (the construction of the two container terminals on the right riverbank) and regional changes. The sole use of the international 1% level to select wetlands of international importance under the Ramsar convention and the efficiency of the currently implemented conservation measures to protect one of the last European whole gradient estuaries are evaluated.

Methods

Study area

The Schelde estuary is situated in the NW of Belgium and the SW of the Netherlands. This macro-tidal estuary is a heterotrophic ecosystem which is under permanent stress caused by a high load of waste water and by extensive dredging activities for the maintenance of shipping traffic to the harbour of Antwerp. The three nature reserves are situated in the Lower Zeeschelde, the section of the Schelde estuary between the Dutch/Belgian border and the town of Antwerpen (Fig. 1). In this estuarine transition zone the river morphology changes from a complex tidal system, with flood and ebb channels between large tidal flats and marshes, into a single tidal channel bordered by relatively small mudflats and marshes. The study area experiences mesohaline salinity conditions most of the time (Baeyens et al., 1998) (Table 1, Van Damme et al., 2004). The mean tidal range is about 4.95 m, ranging between 5.65 m during spring tide and 4 m during neap tide.

The Groot Buitenschuur on the right bank, adjoining downstream to the mudflats and marshes of Waarde, has the largest surface (Table 1); most of it tidal flats, 50 ha flood channel and only 15 ha of tidal marsh. In the sixties a dam was

Table 1. General characteristics of the three study areas

	Galgenschuur	Groot Buitenschuur	Schor Ouden Doel
Distance to river mouth	63–59 km	57–55 km	59–57 km
Tidal marshland	48 ha	15 ha	48 ha
Tidal sand- and mudflats	64 ha	150 ha	46 ha
Total tidal surface area	112 ha	165 ha	94.0 ha
Salinity (1995–2002)	5.4	6.8	6.1
O ₂ saturation (1995–2002)	49%	61%	55%
Vegetation: evolution between 1992 and 1996			
Reed	51–72%	39–52%	20–27%
Cough grass	35–18%	25–11%	33–37%
Alkali bulrush	1–1%	32–35%	32–26%
Macrobenthos: april and september 1997 (Ysebaert et al., 2000)			
Density range	0–15.000 N ₁ /m ²	500–24,000N ₁ /m ²	2.000–35.000 N ₁ /m ²
Max biomass	3.4 g AFDW ₁ /m ²	6 g AFDW ₁ /m ²	15 g AFDW ₁ /m ²
Mean diversity (N ₀)	3.5	4.6	6.6

constructed as a sediment trap in order to reduce dredging activities in the navigation channel (Fig. 1). It changed the morphology of the area considerably, enhancing the formation of a huge sandflat, the Ballastplaat, which is separated from the mudflats by a flood channel. The tidal flats on the Groot Buitenschoor have the most diversified habitat structure, sediment textures vary from very coarse to very muddy and moist with small puddles. The Galgenschuur forms a ribbon between the dike and the water with two third of the surface formed by mudflats and one third marshes. Due to its shape and topography exposure time is relatively short, except for the north site where an erosion-resistant peat layer surfaces, forming a steep cliff between the intertidal and subtidal area. At the beginning of last century both the Groot Buitenschoor and the Galgenschuur were part of 'the tidal flats and marshes of Zandvliet and Lillo', one big intertidal area (820 ha). Nowadays the two nature reserves are squeezed between the river and the harbour industries; separated by two sluices and two container terminals. The Schor Ouden Doel on the left bank is an upstream continuation of the largest European brackish tidal marsh (3500 ha), the 'Verdrongen land van Saeftinghe' where hunting was banned in the eighties. It has an elongated shape with 50% marshes and 50% mudflats and is bordered by the river, the nuclear power station of Doel and the dike with agricultural land beyond it. Vegetation on the three marshes consists mainly of Reed (*Phragmites australis*, Linnaeus), Alkali bulrush (*Scirpus maritimus*, Linnaeus) and Cough grass (*Elymus athericus*, Linnaeus). It is most diverse on Schor Ouden Doel even though cattle's grazing was stopped in 1986. Dominance of Reed vegetations is highest on the Galgenschuur and increased on all three marshes in the nineties (Table 1). Grazing and mowing were introduced as management measures lately to counter this development. Macrobenthic communities on the mudflats are dominated by *Corophium volutator* (Pallas), *Nereis diversicolor* (Müller), *Heteromastus filiformis* (Claparède) and Oligochaeta. Densities and diversities of benthic macrofauna are highest on Schor Ouden Doel and lowest on Galgenschuur (Table 1). The Ballastplaat on the Groot Buitenschoor is nearly void of macrobenthos. Macrozoobenthos on the Galgenschuur is more

dominated by oligochaetes and more related to the upstream oligohaline and freshwater communities than in the other two areas (Ysebaert et al., 1993, 2002).

Bird data

The study covers the period from October 1982 till March 1998. Studied water birds are divers, grebes, cormorants, herons, geese, swans, ducks, coots, waders and terns. Gulls were not included.

The dataset was compiled with personal observations from conservation officers and field ornithologists and with results from different monitoring programs. Since 1982 all three areas were integrated in the monitoring program for waterfowl in Flanders which organises six mid-monthly counts each winter (October–March). Since 1991, the Institute of Nature Conservation started systematic mid-monthly water bird counts in the Zeeschelde from a boat at low tide. On the Groot Buitenschoor numerous observations were made from August 1992 till September 1993, as part of the environmental impact assessment of the construction of the nearby North Sea container terminal. The final data set contained 631 bird counts for the Groot Buitenschoor, 494 for the Galgenschuur and 291 for the Schor Ouden Doel (Table 2). The frequency of the counts differed greatly between years, seasons and areas, because of the multiple data sources. The data set for the Galgenschuur is the most homogeneous, with only a few missing months. For the Groot Buitenschoor data on waders are very numerous and complete, but for the other groups of water birds summer counts are only available since 1992. The data set on the Schor Ouden Doel became very complete since 1991, when it was managed as a nature reserve; until then the only available data were the mid-monthly winter counts from the monitoring program for waterfowl in Flanders

Analysis of data

Numbers of bird-days were calculated, to reduce bias resulting from the heterogeneity of the data set. The number of bird-days between two consecutive bird counts was defined as $[n1 + n2] * [d2 - d1] / 2$ ($n1 + n2$ = the total number of birds for the two counts; $d2 - d1$ = the number of days between the

Table 2. Number of bird counts in winter- (W) and summermonths (S) for each bird-year in each study area (a bird-year runs from july through june of the next year; W = October through March; S = July-September + April-June). For the Groot Buitenschoor waders are mentioned separately because the greater part of the counts concerns waders only

Bird-year	Galgenschoor		Groot Buitenschoor all species		Groot Buitenschoor waders		Schor Ouden Doel	
	W	S	W	S	W	S	W	S
82/83	28	17	6	1	44	56	6	1
83/84	16	15	5	1	19	22	6	
84/85	23	26	6		11	20	6	1
85/86	26	26	4		7	16	6	
86/87	20	11	4		9	18	6	
87/88	19	10	5		13	15	6	
88/89	19	13	6		21	24	10	
89/90	18	11	6		22	21	7	4
90/91	18	6	5		23	22	8	3
91/92	19	12	6	2	16	20	11	7
92/93	18	14	32	28	42	39	19	7
93/94	13	11	8	11	7	11	21	13
94/95	19	6	6	3	7	7	17	7
95/96	13	8	6	5	12	6	22	18
96/97	12	7	7	5	7	13	22	16
97/98	15	5	10	10	10	10	25	16

two counts). Quantitatively the number of bird-days corresponds with the surface area under a line graph of the number of birds for each bird count versus a time scale with day units. This surface area was calculated for each month for each species in each area. Bird-days per month for the Lower Zeeschelde were calculated as the sum of the bird-days for the three separate areas, only for those months with available data for all three areas. The calculated bird-days per month were used for all analyses and calculations, including monthly means, season maxima and season means.

Time was divided in bird-years running from July through June of the next year. Two seasons were distinguished, with winter running from October through March and summer from April through September. Season means were calculated as the mean number of bird-days per month over the months with available count data for that season. Season means for the Lower Zeeschelde were calculated as the sum of the season means for the three separate areas. Unless stated otherwise, observed trends and patterns in species

abundances and species compositions of the water bird communities report on winter data only, because full summer data for all three areas were only available since 1991/1992.

To identify patterns in species compositions log-transformed data ($\log(x + 1)$) on regularly (every bird-year) occurring species were submitted to Principal Component Analyses using STATISTICA version 6.0 (StatSoft Inc.). Factor scores and loadings were used as indicators; deduced trends were verified with Spearman rank correlation coefficients, based on winter means for individual species. Factor scores were submitted to ANOVA and *post hoc* Tukey HSD for unequal numbers to identify significant differences between grouped data.

To calculate population densities, species were grouped in two trophic guilds, according to their habitat use. For benthivores (waders and Common Shelduck *Tadorna tadorna*) only the surface area of mud- and sandflats were considered. To calculate densities of herbivores and omnivores (swans, geese, ducks except for diving ducks and

Common Shelduck, rails) and total bird densities the whole intertidal area (flats and marshes) was taken into account. Piscivores and diving ducks, of minor importance in these areas, were not included in density calculations.

Patterns of relative species abundances were produced by *k*-dominance curves (Magurran, 1988). To identify site specific differences the mean over all winters was calculated for each species. To analyse changes with time, winter means for 4-year periods were calculated.

The 1% level criterion, as it was worked out within the Ramsar convention (Rose & Scott, 1997) is used in this paper as an objective standard to evaluate the evolution of the international importance of the Lower Zeeschelde for water birds. Population estimates for each year were taken from the then current reviews (Atkinson-Willes, 1976; Prater, 1976; Boyd & Pirot, 1989; Monval & Pirot, 1989; Pirot et al., 1989; Smit & Piersma, 1989; Rose & Scott, 1994, 1997; Rose, 1995; Meininger et al., 1995; Scott & Rose, 1996).

To evaluate the impact of climate conditions, the severity of the winters was assessed according to IJnsen (1991). During the study period 1984/1985, 1985/1986, 1986/1987, 1995/1996 and 1996/1997 were assessed as severe winters.

Results

Species composition and seasonal patterns

Overall 68 different species were observed, 20 of which were considered common, with season maxima regularly exceeding 1,000 individuals (Table 3). Greylag Goose (*Anser anser*), Common Shelduck, Common Teal (*Anas crecca*), Wigeon (*Anas penelope*), Mallard (*Anas platyrhynchos*) and Dunlin (*Calidris alpina*) were the most numerous. The number of bird-days per month showed clear seasonal patterns (Fig. 2). Between October 1991 and March 1998 the highest numbers of water birds were counted in December–January, the lowest in August, with an average of 140 000 and 30 000 bird-days per month respectively. Ducks were dominant throughout the year with a maximum in winter; geese were only present in winter and late

autumn. Waders were less numerous and had a less pronounced seasonal pattern, with slightly reduced numbers from March through June. Wigeon, Common Teal, Mallard, Gadwall (*Anas strepera*), Pintail (*Anas acuta*), Tufted duck (*Aythya fuligula*) and Pochard (*Aythya farina*) were typical in winter, Common Shelduck was the dominant duck in summer. Dunlin was the most numerous wader in winter; in summer and autumn Avocet (*Avocetta recurvirostra*) and Lapwing (*Vanellus vanellus*) were more dominant. Ringed plover (*Charadrius hiaticulata*) was typical during autumn migration. Grey plover (*Pluvialis squatarola*) and Bar-tailed godwit (*Limosa lapponica*) showed both spring and autumn migration peaks. Curlew (*Numenius arquata*) was present throughout the year except for the breeding season (April–June).

Total numbers, densities and trophic structure in space and time

Total numbers and densities for the Lower Zeeschelde (sum for the three areas) did not show any clear or continuous trends, season maxima varied between 100 000 and 200 000 bird-days per month. Winter means stabilised more or less around 100,000 bird-days per month the last four years (Fig. 3a). Looking at individual areas, maxima and winter means on the Galgenschoor and Groot Buitenschoor were very variable but the peak seasons levelled out with time (Fig. 3b–c). Changes were more significant on the Schor Ouden Doel, where winter means increased by a factor of four between 1985 and 1990. Since then numbers stabilised (Fig. 3d). Water birds were most numerous on the Groot Buitenschoor but densities were higher on the Schor Ouden Doel. Total numbers and densities on the Galgenschoor were lowest (Table 4).

In winter herbivores and omnivores were most numerous, in summer there were more benthivores (Table 4). The trophic structure of the water bird communities in winter changed with time. The benthivore numbers declined (not significantly, Table 5) on the Groot Buitenschoor and the Galgenschoor. On the Schor Ouden Doel herbivores and omnivores increased significantly in numbers (Fig. 3a–c).

Table 3. Bird-year maxima (bird-days/month) for the most common waterbird species in the Lower Zeescheide. Bird-years run from July through June

Species/bird-year	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98
Cormorant <i>Phalacrocorax carbo</i>	289	938	768	460	445	950	536	280	1,002	282	821	1,416	1,190	1,180	1,282	801
Great crested Grebe <i>Podiceps cristatus</i>	159	142	1,771	170	271	1,347	916	470	2,195	127	1,245	692	807	2,054	717	1,552
White-fronted Goose <i>Anser albifrons</i>	936	1,646	2,457	1,135	2,357	3,083	820	226	10,765	548	2,400	588	38	428	3,204	6,863
Greylag Goose <i>Anser anser</i>	23,117	23,429	25,499	25,438	67,853	28,109	47,681	69,694	61,818	42,049	71,076	82,320	60,193	47,420	67,080	58,035
Common Shelduck <i>Tadorna tadorna</i>	4,933	6,284	63,315	17,974	8,870	27,018	17,440	20,652	8,322	31,274	32,162	13,394	28,401	17,822	29,272	18,866
Wigeon <i>Anas penelope</i>	8,086	8,007	10,781	9,706	15,841	13,038	23,432	12,242	25,427	19,230	27,455	43,068	28,699	51,906	89,830	40,936
Gadwall <i>Anas strepera</i>	180	178	402	18	461	639	617	878	2,392	1,188	5,468	3,433	2,720	2,074	2,615	2,889
Common Teal <i>Anas crecca</i>	14,273	25,982	62,977	10,265	14,382	21,698	26,647	17,466	37,881	18,602	22,622	14,677	20,386	19,834	10,890	12,274
Mallard <i>Anas platyrhynchos</i>	58,081	33,346	30,091	32,454	34,784	39,470	36,205	42,204	18,262	21,469	20,405	15,032	7,359	8,593	7,446	11,347
Pintail <i>Anas acuta</i>	5,116	1,453	5,582	1,706	1,444	11,143	3,606	7,984	7,801	1,332	4,695	3,182	1,900	919	5,978	1,146
Shoveler <i>Anas clypeata</i>	15,719	4,811	16,987	667	110	10,701	9,293	930	1,353	429	1,002	518	196	1,548	1,965	122
Oystercatcher <i>Haematopus ostralegus</i>	3,235	2,971	2,006	1,198	3,127	1,101	844	1,345	1,523	1,478	3,472	3,990	1,496	2,677	2,075	1,769
Avocet <i>Recurvirostra avosetta</i>	3,454	6,396	2,304	1,794	5,604	3,241	4,268	7,503	4,881	5,051	6,398	3,753	27,259	16,669	6,723	5,813
Ringed Plover <i>Charadrius hiaticulata</i>	4,038	1,282	1,745	4,324	4,742	3,170	473	3,527	2,851	330	4,119	3,986	952	1,822	1,589	4,168
Grey Plover <i>Pluvialis squatarola</i>	2,648	2,844	2,839	2,222	1,645	256	967	1,828	1,561	4,706	3,597	1,677	1,331	2,344	2,663	2,902
Lapwing <i>Vanellus vanellus</i>	3,385	2,816	3,206	4,635	2,274	4,596	4,344	7,568	5,676	3,986	3,598	4,659	6,072	5,566	5,532	7,118
Dunlin <i>Calidris alpina</i>	50,622	54,710	49,590	48,531	4,159	623	14,604	16,119	51,098	69,724	4,017	3,596	7,663	18,137	22,323	5,755
Bar-tailed Godwit <i>Limosa lapponica</i>	2,258	3,356	2,638	3,049	3,111	378	2,294	1,009	2,318	5,242	1,297	416	713	513	838	584
Curllew <i>Numenius arquata</i>	5,028	4,234	4,217	3,071	2,639	1,271	1,359	1,156	1,876	2,788	3,004	2,161	3,197	3,206	3,309	2,742
Redshank <i>Tringa totanus</i>	847	689	532	381	307	283	649	1,136	732	953	2,303	1,527	678	1,306	1,005	1,573

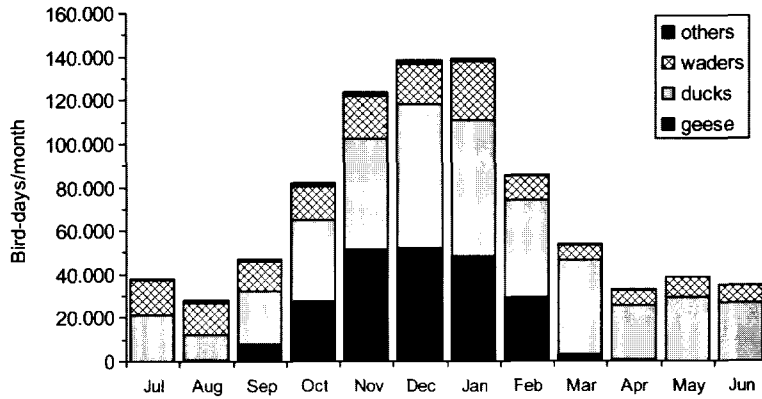


Figure 2. Seasonal patterns in the Lower Zeeschelde between October 1992 and March 1998.

Species composition in space and time

Beside seasonal effects, observed species compositions also differed between the three areas and between bird years. Results from a PCA, on log-transformed bird-days per month for the 29 most common species, suggest location to be the most discriminating factor for species composition in winter, followed by year to year variations. Factor scores for the 1st (12.3% of the observed variance) and 2nd (11.6%) principal components

were submitted to ANOVA, grouped respectively by location ($p < 0.001$ for PC1 and PC2), winter season (PC1: $p < 0.05$; PC2: $p < 0.001$) and month (PC1: $p > 0.05$; PC2: $p > 0.001$). The first principal component groups the Galgenschoor and the Schor Ouden Doel, separating the Groot Buitenschoor (*post hoc* Tukey HSD for unequal numbers, $\alpha = 0.001$). Pintail, Shoveler (*Anas clypeata*), Oystercatcher (*Haematopus ostralegis*), Dunlin, Mallard and Grey Plover were identified as distinguishing species. The second principal

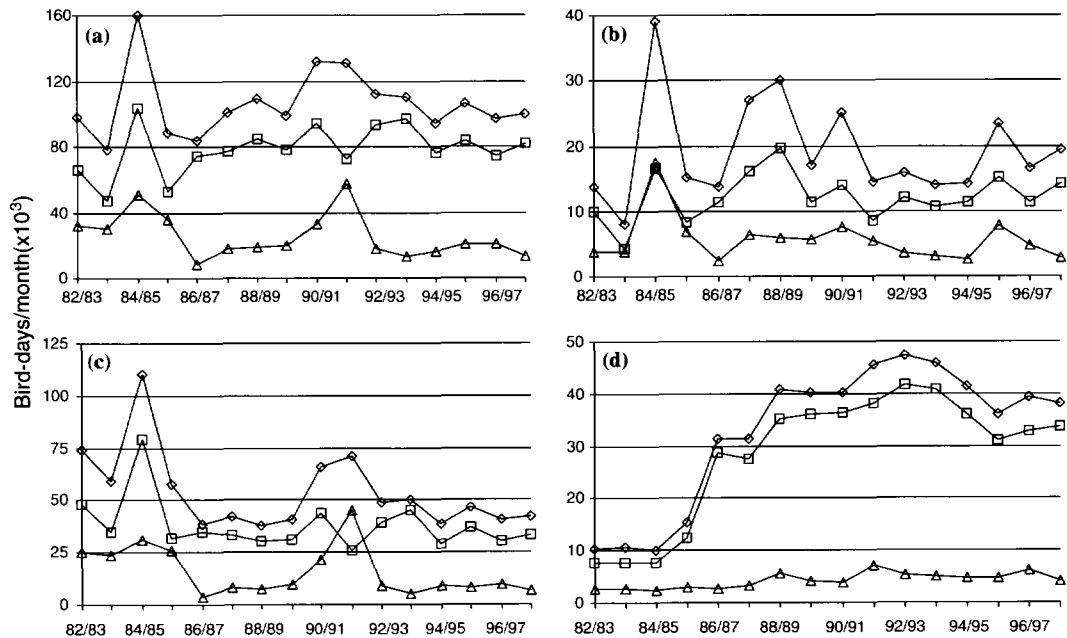


Figure 3. Trends in the wintermeans (bird-days/month) for waterbirds (Δ benthivores, \square herbi- and omnivores, \diamond total number): (a). Lower Zeeschelde; (b). Galgenschoor; (c). Groot Buitenschoor; (d). Schor Ouden Doel.

Table 4. Mean numbers (N) and densities (D) of herbivores and omnivores, benthivores and all waterbirds on the Galgenschoor, Groot Buitenschoor, Schor Ouden Doel and in the Lower Zeeschelde calculated for summer, winter, and through a complete bird-year for the period 1991/1992–1997/1998

	Galgenschoor		Groot Buitenschoor		Schor Ouden Doel		Lower Zeeschelde	
	N	D (N/ha)	N	D (N/ha)	N	D (N/ha)	N	D (N/ha)
Herbi/omnivores								
Winter	329	3.5	1.200	7.3	1.253	13.3	2.799	7.5
Summer	56	0.5	101	0.6	98	1.0	241	0.6
Bird-year	188	2.1	649	4.1	687	7.3	1.817	4.9
Benthivores								
Winter	146	2.3	413	2.9	174	3.7	766	2.9
Summer	125	2.0	675	4.5	205	4.4	957	3.7
Bird-year	138	2.1	532	3.5	184	3.9	842	3.2
Total								
Winter	547	4.8	1.658	9.9	1.436	15.1	3.611	9.6
Summer	184	1.6	776	4.7	307	3.2	1.198	3.2
Bird-year	380	2.8	1.310	6.3	886	9.3	2.698	7.2

component separates the Galgenschoor (*post hoc* Tukey HSD for unequal numbers, $\alpha = 0.001$), characterised by lower numbers of Greylag Goose, Wigeon and White-fronted Goose (*Anser albifrons*) (Fig. 4).

The most striking trends in the overall species composition in winter for the Lower Zeeschelde during the study period were the increasing numbers of Greylag Goose, Wigeon and Gadwall and a decrease for Mallard. Winter means for

Table 5. Spearman rank correlation coefficients (r_s) and p -values based on winter means between 1982/1983 and 1997/1998 ($N = 16$)

	Galgenschoor			Groot Buitenschoor			Schor Ouden Doel			Lower Zeeschelde		
	R	p -level		R	p -level		R	p -level		R	p -level	
Total numbers	0.191	0.478	ns	-0.444	0.085	ns	0.650	0.006	**	0.194	0.471	ns
Herbivores	0.191	0.478	ns	-0.312	0.240	ns	0.647	0.007	**	0.347	0.188	ns
Benthivores	-0.232	0.387	ns	-0.429	0.097	ns	0.747	0.001	***	-0.382	0.144	ns
Greylag Goose	0.922	0.000	***	0.700	0.003	***	0.771	0.000	***	0.897	0.000	***
Common	-0.435	0.092	ns	0.112	0.680	ns	-0.200	0.458	ns	-0.144	0.594	ns
Shelduck												
Wigeon	0.877	0.000	***	0.794	0.000	***	0.747	0.001	***	0.915	0.000	***
Gadwall	0.862	0.000	***	0.437	0.091	ns	0.649	0.007	**	0.888	0.000	***
Common Teal	-0.468	0.068	ns	0.100	0.713	ns	0.679	0.004	***	0.050	0.854	ns
Mallard	-0.653	0.006	**	-0.871	0.000	***	0.106	0.696	ns	-0.818	0.000	***
Pintail	-0.447	0.083	ns	-0.365	0.165	ns	0.521	0.039	*	-0.353	0.180	ns
Shoveler	-0.024	0.931	ns	-0.544	0.029	*	0.127	0.638	ns	-0.544	0.029	*
Oystercatcher	-0.074	0.787	ns	-0.176	0.513	ns	0.671	0.004	***	-0.003	0.991	ns
Avocet	0.241	0.368	ns	0.332	0.208	ns	0.376	0.151	ns	0.541	0.030	*
Grey Plover	-0.661	0.005	**	-0.496	0.051	ns	0.529	0.035	*	-0.491	0.053	ns
Dunlin	-0.085	0.753	ns	-0.497	0.050	ns	0.605	0.013	*	-0.338	0.200	ns

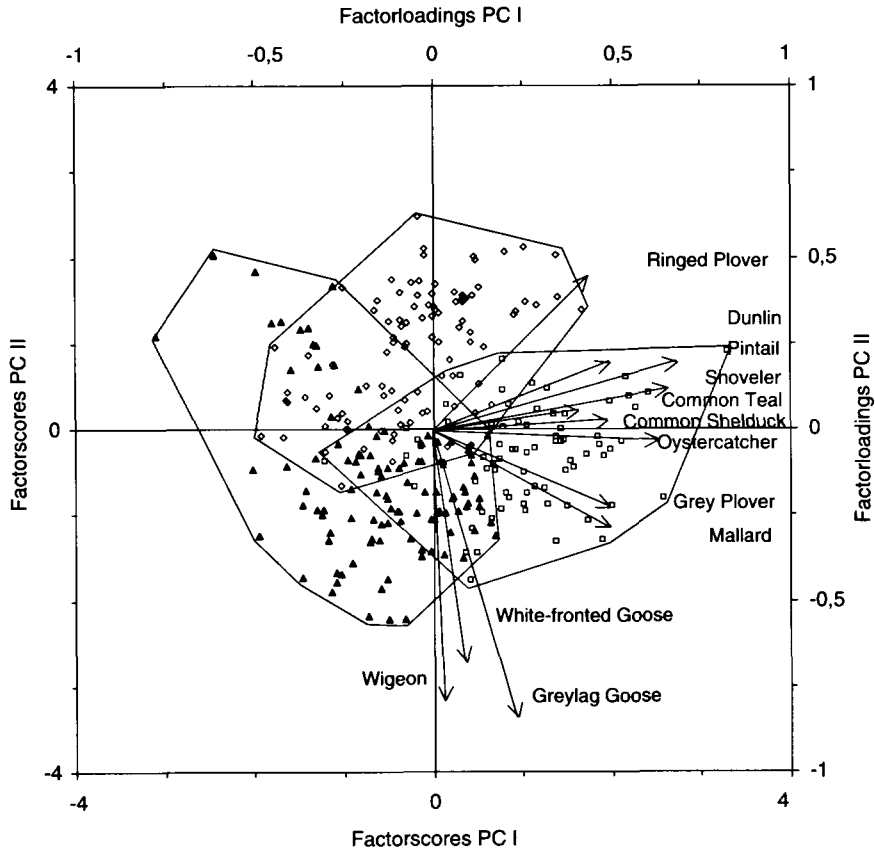


Figure 4. Biplot of factorscores and factorloadings in the 1st and 2nd principal components derived from a principal component analysis using log-transformed bird-days per month for 29 waterbird species in winter on Galgenschoor (\diamond), Groot Buitenschoor (\square) and Schor Ouden Doel (\triangle). The arrows represent factorloadings for the most characteristic species.

Common Shelduck, Shoveler and Dunlin were highly variable, with a, not significant, negative overall trend (Fig. 5, Table 5). However, species composition did not change in the same way and to the same extent in each of the three areas. In Fig. 4 the factor scores in the centre, where the three areas overlap, mostly deal with the more recent observations. This suggests that species compositions for Galgenschoor, Groot Buitenschoor and Schor Ouden Doel evolved from more different water bird communities towards more similar ones. This trend was further evidenced by a PCA on log-transformed winter means for each area, eliminating effects caused by monthly patterns (Fig. 6). The first two principal components account for 18.1 and 16.3%, respectively, of the observed variance. PC I differentiates between the Schor Ouden Doel and Groot

Buitenschoor, PC II separates the Galgenschoor (*post hoc* Tukey HSD, $\alpha = 0.001$). Initially the three areas scored quite differently but scores for the last winters all concentrate in the centre of the ordination diagram. This evolution is the combined effect of changes in the (relative) abundances of some species in each area (Figs. 5 and 6).

Greylag Goose (herbivore) was at first almost restricted to the Groot Buitenschoor, using the area as a resting and refuge place, but as their numbers increased, they moved into the Schor Ouden Doel (also used for foraging) and some limited numbers were also noticed on the Galgenschoor. Common Shelduck (benthivore) was at first very numerous on the right bank. However, winter numbers on the Galgenschoor dropped in the nineties below those for Schor Ouden Doel. On the Groot Buitenschoor its

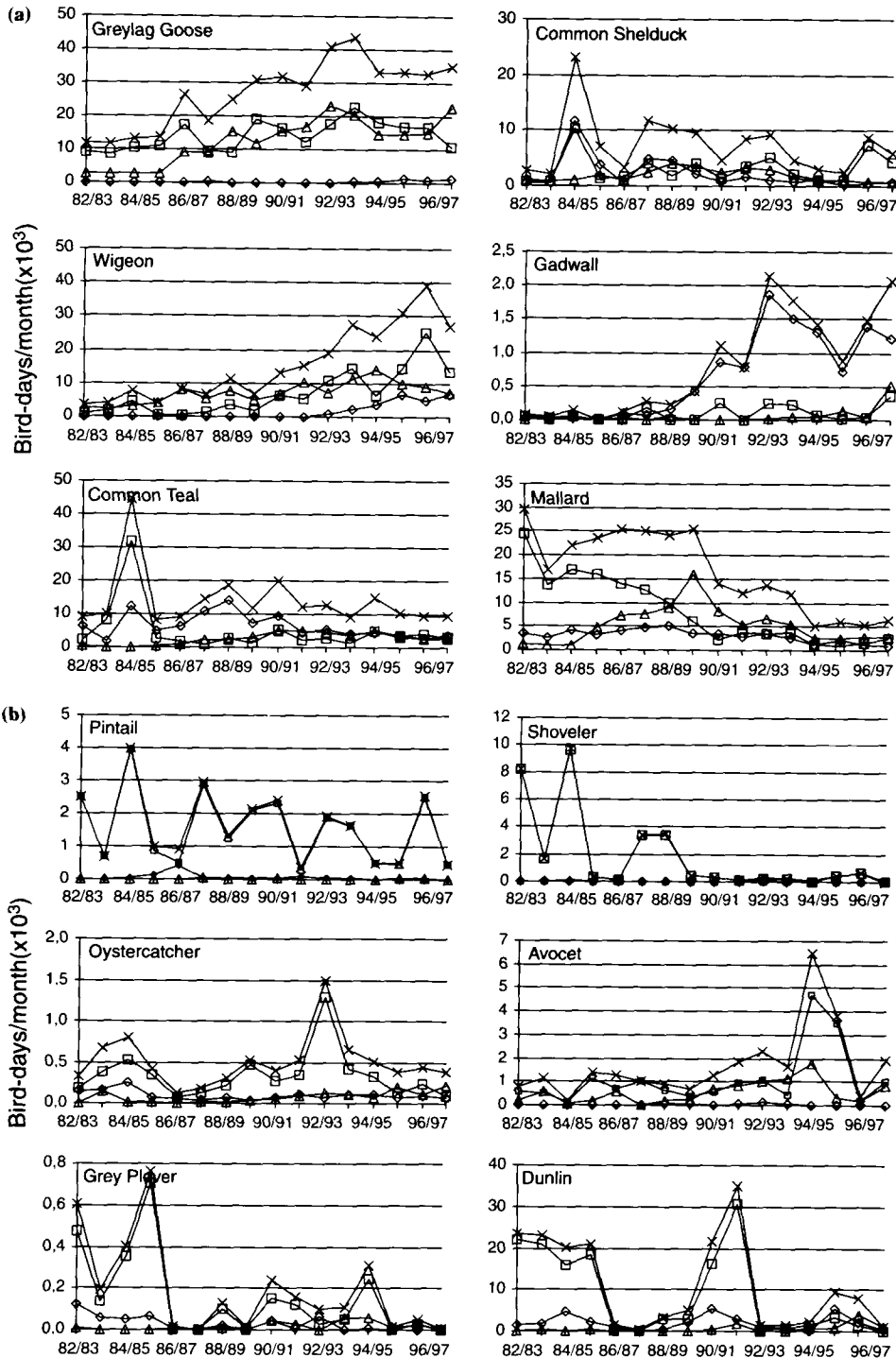


Figure 5. (a) Evolution of the wintermeans (bird-days, month) for Greylag Goose, Common Shelduck, Wigeon, Gadwall, Common Teal, Mallard on the Galgenschoor (\diamond), Groot Buitenschoor (\square), Schor Ouden Doel (\triangle) and in the Lower Zeeschelde (\times). (b) Evolution of the wintermeans (bird-days, month) for Pintail, Shoveler, Oystercatcher, Avocet, Grey Plover and Dunlin on the Galgenschoor (\diamond), Groot Buitenschoor (\square), Schor Ouden Doel (\triangle) and in the Lower Zeeschelde (\times).

presence is very variable in winter. Wigeon (herbivore) was the most abundant species on the Schor Ouden Doel during the first winters. As its total numbers increased, it also became more general in the other two areas. Gadwall (herbivore), a typical wintering species, was very limited in the first half of the eighties, but since then the numbers increased gradually. The species is by far most abundant on the Galgenschoor but observations became also more frequent in the other two areas. Common Teal (omnivore) was the most dominant species on the Galgenschoor. Gradually their numbers declined in this area but they increased on the Groot Buitenschoor and the Schor Ouden Doel. Mallard (omnivore) was most observed on the Groot Buitenschoor but numbers declined there and for the last winters they were

almost equal in the three areas. Pintail (herbivore) was nearly restricted to Groot Buitenschoor, its numbers are highly variable but the overall trend is negative.

Avocet (benthivore) was most numerous on the Groot Buitenschoor, but with very variable winter maxima. Dunlin (benthivore) was the most dominant species on the Groot Buitenschoor but after 85/86 their presence was much less there dominant and more comparable for the three areas (except for the winters 90/91 and 91/92). Observed numbers for Oystercatcher, Curlew, Common Redshank, Spotted redshank, Common greenshank, Common sandpiper and Common snipe (benthivores) decreased slightly. Initially they were most observed on the right bank but the numbers became more comparable in the three areas as they

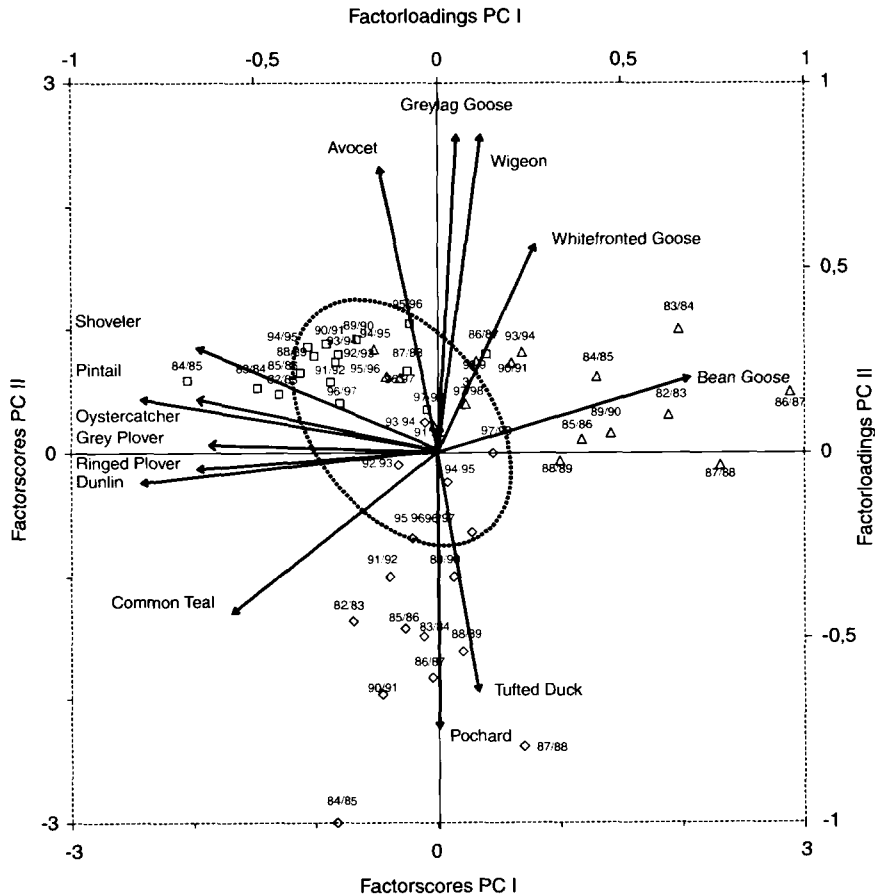


Figure 6. Biplot of factorscores and factorloadings in the 1st and 2nd principal components derived from a principal component analysis using log-transformed wintermeans per month for 29 waterbird species in winter on Galgenschoor (◇), Groot Buitenschoor (□) and Schor Ouden Doel (△). The arrows represent factorloadings for the most characteristic species, the oval shape encloses factorscores for the last four winters (94/95–97/98).

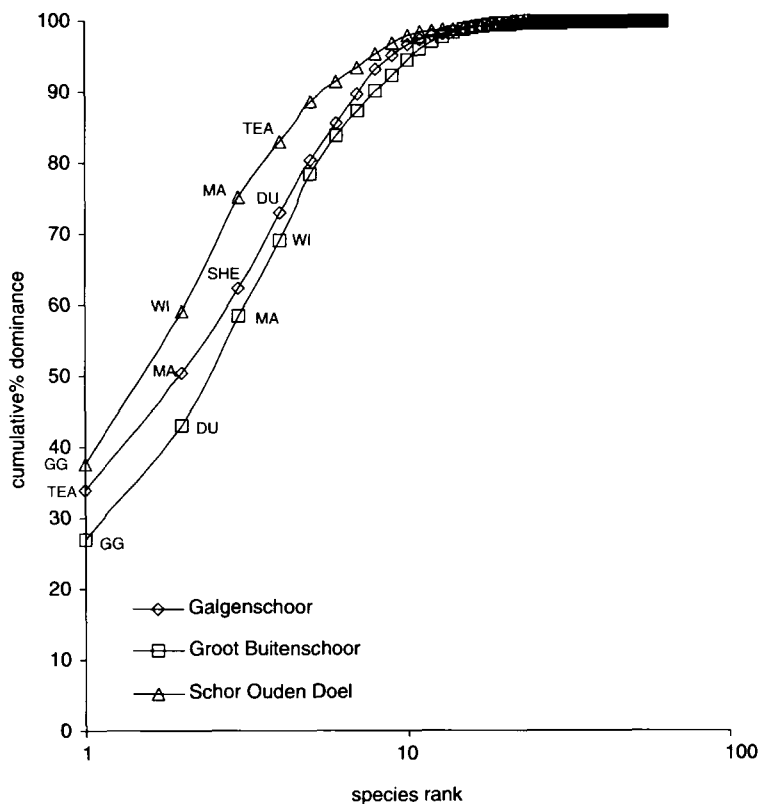


Figure 7. *k*-dominance curves for waterbirds in winter on the Galgenschoor (◇), Groot Buitenschoor (□) and Schor Ouden Doel (△) (GG = Greylag Goose, WI = Wigeon, MA = Mallard, TE = Common Teal, DU = Dunlin, SHE = Common Shelduck).

decreased on the right bank and increased on Schor Ouden Doel.

Some less abundant species, largely confined to one area (Bean Goose on the Schor Ouden Doel, Shoveler and Ruff on the Groot Buitenschoor and Pochard and Tufted Duck on the Galgenschoor), decreased in numbers or disappeared. As a result their impact on the difference in species composition between the three areas decreased.

Diversity patterns in space and time

The water bird community in winter was dominated by only a few species. This was most pronounced on the Schor Ouden Doel, where Greylag Goose and Wigeon together represented 59% of all observations. Dominance was least pronounced on the Groot Buitenschoor (Fig. 7).

Despite clear shifts in the species composition the observed *k*-dominance curves only slightly

changed in time, with a tendency of increased dominance of a few species in the lower Zeeschelde during the last winters (Fig. 8). In the four first winters Mallard and Dunlin were most dominant, in the last four winters Greylag Goose and Wigeon took over dominance (Fig. 8a). The results for the Lower Zeeschelde are mostly influenced by evolutions on the Groot Buitenschoor and the Schor Ouden Doel because of their higher total numbers. On the Groot Buitenschoor Dunlin and Mallard (19 and 18% in the first four winters) were outnumbered by Greylag Goose and Wigeon (37 and 23% in the last winters (Fig. 8c). On the Schor Ouden Doel the same species, Wigeon and Greylag goose, remained dominant but their dominance increased (Fig. 8d). Observations on the Galgenschoor developed in a different way, *k*-dominance rather decreased as compared to the first years, and Wigeon became the most dominant species (Fig. 8b).

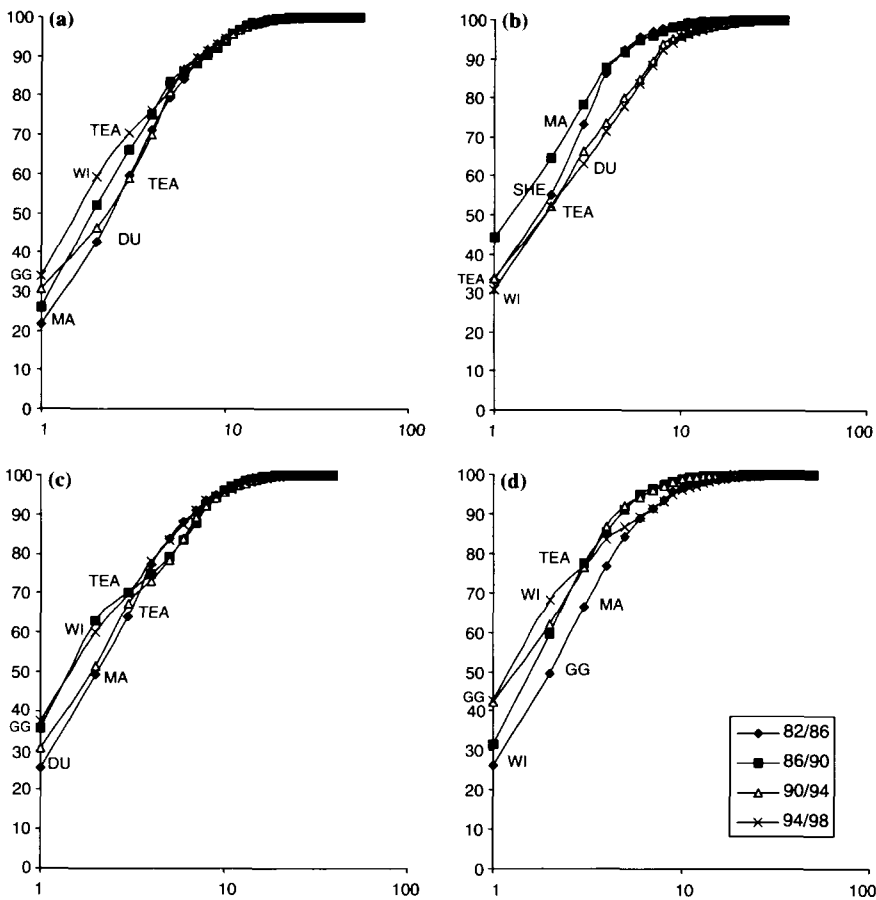


Figure 8. Evolution of the k -dominance curves for waterbirds in winter in (a) the Lower Zeeschelde (b) the Galgenschoor. (c) the Groot Buitenschoor and (d) the Schor Ouden Doel (\diamond : 82/86, \square : 86-90, \triangle : 90-94 and \times : 94-98). DU = Dunlin. GG = Greylag Goose. MA = Mallard. SHE = Common Shelduck. TEA = Teal. WI = Wigeon.

International importance

Except for 83/84 and 85/86, the international 1% level was always exceeded by one or more species (Table 6). Initially Shoveler and Ringed plover occasionally exceeded the 1% level on the Groot Buitenschoor, but not any more in the nineties. Their numbers declined, meanwhile the 1% level increased. The numbers of Greylag goose on the Groot Buitenschoor and Schor Ouden Doel kept pace with the Northwest-European population growth, since 88/89 the 1% level was exceeded every bird-year. The Galgenschoor was of international importance for Gadwall in the first half of the nineties. The numbers did not decline later, but the population estimate doubled from 150 to 300 in 95/96. The 1% was exceeded once by Common

Teal and Avocet on the Groot Buitenschoor and by Common Shelduck on the Galgenschoor.

Discussion

In this study the counting methods, frequency of counting, experience of the field ornithologists and tidal conditions were very heterogeneous. Several authors stress on the importance of uniformity in data gathering with regard to all these factors when compiling results from different monitoring programs for water birds in one area (Underhill & Prys-Jones, 1994; Yates & Goss-Custard, 1991). Despite the integration of all data into one dataset caution is still called for when interpreting trends and patterns. Especially the effect of differences in

Table 6. International importance of the Lower Zeeschelde through the study period: 1% for the international important species at the beginning and the end of the study period. Maximum % of the Northwest-European population for international important species in each bird-year

Max. % pop	1% level	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98
Greylag goose	1200–2000					1.89		1.32	2.56	1.71	1.21	2.8	2.28	1.96	1.31	1.12	1.55
Common shelduck	1300–3000			2.12													
Gadwall	50–300									1.35	1.15	2.43	2.02	1.12			
Common teal	2000–4000			1.05													
Shoveler	200–400	3.25		3.27			2.02	1.85									
Avocet	700														1.65		
Great ringed plover	200–500	1.11				1.6	1.52										

monitoring frequencies might bias observed patterns for species that migrate through the area for a very short time period, or use the area irregularly as a refuge.

Nevertheless, the results of this study confirmed and evidenced the importance of the Lower Zeeschelde as foraging and resting habitat for migrating water birds. Expressed as the total number of bird-days per bird-year the functionality of the area did not change or show any steady trend during the study period but some striking trends and patterns in the community structure were traced. Observed species compositions differed between areas due to habitat differences, between months because of seasonal patterns, and between bird years because of local and regional habitat changes, population developments and climate conditions. According to the PCA results differences between the three areas ranked above changes with time and seasonal patterns with respect to their impact on the water bird communities in winter.

Spatial patterns

Available habitat surface, the amount and type of food resources (which are in turn affected by water quality, salinity, tidal and hydrodynamic regime, sediment and soil texture and moisture), the configuration of the site and available feeding time affect the number and species of water birds on an intertidal area (Goss-Custard et al., 1991; Hill, et al., 1993; Yates et al., 1993; Zwarts, 1996; Rosa et al., 2003). Also the vicinity of suitable

non-intertidal habitat is considered essential as high water roost and additional feeding ground for various waders, contributing to the maintenance of high densities of foraging waders on mudflats (Masero et al., 2000; Long & Ralph, 2001; Smart & Gill, 2003).

At the scale of the estuary, a clear change in waterbird populations is observed along the salinity gradient in the Schelde (Ysebaert et al., 2000), related to available surface area, habitats and food. Most waders (benthivores) are hosted in the polyhaline zone because of the large sand and mud flats and a high benthic biomass. Geese and Wigeon (herbivores) concentrate in the mesohaline part near the very large saltmarsh Saeftinghe and the oligohaline and freshwater areas are dominated by duck species such as Teal and Gadwall. Common Shelduck and Mallard are found along the complete salinity gradient. The differences between the water bird populations on Galgenschoor, Groot Buitenschoor and Schor Ouden Doel can be related to their specific geographic position along this steep estuarine gradient, their habitat size, shape and suitability and the land use in the near vicinity (Fig. 1, Table 1). On the Galgenschoor, the most upstream area, the highest numbers of Common teal, Gadwall, Tufted duck and Pochard were observed, as such resembling the oligohaline and freshwater bird communities. Because of its low prey densities, restricted available feeding time, monotonous reed vegetation and lack of inland roosts and feeding grounds, the Galgenschoor offered the least interesting foraging and resting habitat for both herbivores and

benthivores. On the Groot Buitenschoor the large sand flats were an ideal refuge and resting place for high numbers of Greylag goose and Wigeon. The diverse mudflats with the flood channel, the continuation of the mudflat downstream on the Dutch side, hosted a diverse community of mainly benthivores. Numbers of Plovers, Dunlin, Oystercatcher, Avocet, Curlew, Shoveler and Pintail were highest in this area. Because of the very small marsh, foraging herbivores were only observed in very low numbers. On the Schor Ouden Doel the presence of nearby inland fields and pastures and the close relationship with Saeftinghe were reflected in high numbers of Greylag goose and Wigeon and the presence of other goose species. Most of the wader species were relatively well represented. The Schor Ouden Doel had the best quality habitat for both trophic groups. Numbers of Mallard were comparable in the three areas. Common Shelduck was by far the most typical species for the Groot Buitenschoor which used to be an important moulting place for this species (Voet, 1982). In the late nineties moulting Shelducks were rarely observed. This was not adequately evidenced by the results of analyses on winter data, because it was a typical summer species.

Patterns in time

Year to year changes in waterbird communities on intertidal areas are affected by population developments and habitat changes (Tamisier & Grillas, 1994, Rehfish et al., 2003). The water bird populations in the study area, being relatively small, are affected by trends in the regional (scale of the estuary) and geographic populations.

Major relevant changes in the Northwest-European water bird populations during the study period were the increases in the population estimates and 1% levels for Greylag Goose, Common Shelduck, Wigeon, Gadwall, Common Teal, Oystercatcher, Great Ringed Plover and Grey Plover (Table 6). Besides genuine population trends, the new estimates also reflect the improved completeness of the monitoring programs and the application of optimised computing methods to account for gaps in datasets (Green, 1995; Rose & Scott, 1997; Kershaw & Cranswick, 2002). In the whole Schelde estuary, these trends were followed

to a large extent except for Grey plover which declined (Table 7). Moreover Pintail and Dunlin increased in numbers.

During the study period the number of bird-days/year increased substantially on the left bank of the Lower Zeeschelde and varied greatly on the right bank. The Lower Zeeschelde became more important as wintering and resting place for herbivores. The increased numbers of Greylag goose, Wigeon and Gadwall were disproportionate to the estimated population increases. This was due to the ban on hunting in Saeftinghe, migration shifts from the traditional wintering grounds in Spain towards Northwest-Europe for Greylag goose (Nillson et al., 1999) and improved water quality conditions in the oligohaline and freshwater tidal part of the Zeeschelde for Gadwall. On the other hand, the function of the lower Zeeschelde as feeding ground and stop-over site for benthivores during spring and autumn migration became relatively less important. On the right bank the combined food and rest situation became possibly less optimal and attractive to migrating birds; the progressive occupation of inland areas by harbour-related infrastructure reduced inland high tide roosts and feeding grounds and increased disturbance. There were no explanatory factors for the overall declining numbers of Mallard and Shoveler. The decline for Common Teal since 1990 in the Lower Zeeschelde matched the evolutions in the Western Schelde (Meininger et al., 1998) but at the same time observed numbers of this species in the upstream Zeeschelde increased disproportionately to the Northwest European population growth, because of improved environmental conditions (Ysebaert et al., 2000). It could be argued that Common Teal, a typical freshwater species in the Schelde estuary, moved from the brackish areas to the preferred oligohaline and freshwater zones as the habitat quality improved there but hard evidence eg. from tagged individuals to support this hypothesis was lacking.

Seasonality

Some species showed very distinct winter and/or migration peaks, others however had a more variable seasonal pattern according to winter

Table 7. Spearman rank correlation coefficients (r_s) and p -values based on winter means for some water bird species in the Schelde estuary 91–98 (data compilation from the Westerschelde and Zeeschelde monitoring program). For each species the area where the highest numbers are observed along the estuarine gradient of the Schelde estuary is indicated (see also Ysebaert et al. 2000) ($N = 7$)

	Westerschelde			Zeeschelde			Schelde estuary			Area
	R	p -level		R	p -level		R	p -level		
Greylag Goose	0.929	0.003	***	0.179	0.702	ns	0.929	0.003	***	Mesohaline
Common Shelduck	-0.036	0.939	ns	0.071	0.879	ns	-0.179	0.702	ns	Whole estuary
Wigeon	0.821	0.023	*	0.857	0.014	ns	0.821	0.023	*	Mesohaline
Gadwall	0.286	0.535	ns	1.000		***	1.000		***	Oligohaline-fresh-water tidal
Common Teal	0.393	0.383	ns	0.679	0.094	ns	0.714	0.071	ns	Freshwater tidal
Mallard	0.179	0.702	ns	0.429	0.337	ns	0.107	0.819	ns	Whole estuary
Pintail	0.286	0.535	ns	0.643	0.119	ns	0.679	0.094	ns	Mesohaline
Shoveler	-0.321	0.482	ns	0.000	1.000	ns	-0.107	0.819	ns	Mesohaline
Oystercatcher	0.107	0.819	ns	0.179	0.702	ns	0.107	0.819	ns	Polyhaline
Avocet	-0.429	0.337	ns	0.107	0.819	ns	-0.286	0.535	ns	Polyhaline-mesohaline
Grey Plover	-0.857	0.014	*	-0.378	0.403	ns	-0.857	0.014	*	Polyhaline
Dunlin	0.500	0.253	ns	-0.179	0.702	ns	0.286	0.535	ns	Polyhaline

severity and the resulting food shortage and population dynamics. Varied winter effects were noticed during the study period for Common Shelduck, Wigeon, Common Teal, Pintail and Tufted duck. During short or moderate winter spells, the Lower Zeeschelde attracted higher numbers of waterfowl from inland and up North. When these conditions persevered, numbers reduced below average because the waterfowl moved to more moderate areas (Ridgill & Fox, 1990; Melftofte et al., 1994). The lower numbers of observed waders at the end of the eighties could be related to the cumulative effect of the three consecutive severe winters from 1984 to 1987. (Meininger et al., 1991, 1994). On the other hand the Lower Zeeschelde was situated on the edge of the distribution range for most of the wader species (Ysebaert et al., 2000). Such areas might serve as overflow in times of food shortage or population peaks (van der Have et al., 1984). Seasonality and response to the above-mentioned factors differed greatly between Groot Buitenschoor, Galgenschoor and Schor Ouden Doel. Each area served at specific times and/or for different functions for Greylag Goose, Common Shelduck, Wigeon, Oystercatcher, Avocet, Lapwing, and Common Redshank.

Impact of the container terminals and port development

Some observed trends suggest the following cause-effect relationship with the construction of the container terminals: due to direct habitat loss and increased disturbance on the right bank wintering Dunlin and migrating waders in spring and autumn shifted to Schor Ouden Doel, where hunting was banned. Common Shelduck shifted downstream for moulting to the sand flats of Valkenisse, where increasing numbers of moulting Shelduck were observed during the study period (data not shown). In several studies construction works and increased and sustained disturbance associated with urbanisation and industrialisation were found to reduce local habit quality for migrating water birds and the carrying capacity of estuaries (Mitchell et al., 1988; Martin et al., 2000; Burton et al., 2002a,b). Responses of water birds and their prey items to habitat loss have equally been evaluated and predicted through modelling in various studies (Goss-Custard et al., 1991, 1995, 1997; Yates & Goss-Custard, 1992). Population decline was the most obvious response. However, the relationship was not linear because of the interference with several factors such as relative

abundance of breeding and wintering habitat, carrying capacity, migration shifts, individual strategic decisions and genetic mechanisms. In this study, several other aspects increased the complexity of interacting factors. It takes decades, rather than years to separate significant time trends in populations from year to year variability (Krebs, 1991). The construction of the container terminals was only one aspect of an ongoing evolution in the Lower Zeeschelde and the lost habitat was relatively small, hence its effect was hard to isolate. The observed trends might be indicators of possible impacts, but a longer term is needed to be conclusive.

Biodiversity conservation and estuarine management: an evaluation

Together with the inland polders the Lower Zeeschelde was designated as Bird directive area for its important numbers of some annex I and internationally important species (e.g. Avocet, Golden Plover, Ruff, Greylag Goose, Bean Goose, White fronted Goose, Common Shelduck, and Shoveler) and as a Ramsar site for its internationally important numbers of some migrating bird species along the East-Atlantic flyway. Even though the area was threatened by the expanding harbour its use by water birds was also highly influenced by external factors (local, regional and geographical population trends). In almost every season some species reached the international 1% level but the species involved changed as a result of population dynamics and changes in adjacent and distant areas. In the nineties the study area became a key site for Greylag goose because of the very high numbers during more than five consecutive winters (Scott & Rose, 1996). The sole use of the 1% criterion for specified species to designate Ramsar sites is too simple and risky. Especially in smaller areas specific species abundances can be very temporary. They are unpredictable on longer terms and the disappearance of a certain species is not always related to deterioration of the site. At least some of the more manageable and predictable qualitative habitat criteria (criteria for representative or unique wetlands; criteria based on plants and animals, Frazier, 1996, Scott & Rose, 1996) should be included in the designation criteria since a complementary set of indicators is a more

reliable indicator to evaluate developments of a given site.

Despite their conservation status valuable habitats are still subject to destruction as was the case in this study. The Lower Zeeschelde was added to the Montreux record of threatened sites (Davis, 1994) because of the harbour expansion activities but so far this did not prevent any infrastructure works to proceed. International legislation also enforces compensation measures prior to habitat destruction in or near protected sites. Destruction of 8 ha intertidal habitat for the North sea container terminal was compensated for by the restoration of 30 ha of intertidal area on the Ketenssepolder. Even though the compensated area was much larger, it did not restore the enhanced fragmentation of the Groot Buitenschoor and Galgenschoor. Moreover, compensation was only implemented in 2001, 6 years after the completion of the container terminal, while restored intertidal habitats for birds need to develop at least 3 years before they become eventually profitable for foraging waterbirds (Evans et al., 1998). After 20 years of implementation, the effectiveness of the Ramsar convention for the protection of migrating waterbirds was evaluated by several countries (Gerakis & Kalburtji, 1998; Hurstel & Sanné, 1998; Keller, 1998; Mitlacher, 1998). In general conclusions most of the important sites were protected but fragmentation and the small size of the protected sites were sometimes considered as a threat. Moreover, the juridical protection of these sites did not warrant the active conservation of their ecological values. Water management, river regulation, intensive agriculture, industrialisation, pollution and recreation near and in the sites were cited as the most important threats. For water bird protection, water and its use across the landscape was considered more important than the spatial arrangement of a fixed array of reserves (Roshier et al., 2002). More benefit was expected from integrated ecosystem management plans, including societal functions and private properties instead of isolated management plans for protected areas only (Tamisier & Grillas, 1993). Transboundary wetland management should ensure adequate migration pathways for all relevant water bird species. Juridical site protection is only one of the tools in this management process.

Similarly the lower Zeeschelde is just one link in several chains. It derives its ecological importance from its position in the complete estuarine gradient, the habitat quality and function of the adjacent valley and its function along the East Atlantic flyway. Intensification of agriculture and harbour expansion in the polders on the left bank threatens its key site statute for Greylag goose. Diversity of its bird populations relies greatly on the continuity of the habitat gradient along the estuary (Ysebaert et al., 2000) and its function in the East Atlantic flyway relies on evolutions in neighbouring stop-over sites (Piersma, 1987). To safeguard its ecological functions in all of these aspects its protection and management should be part of an integrated management plan for the estuary and its valley. In estuaries it is the diversity of ecological processes, and in particular certain keystone processes, that is more critical and that should be the focus of management efforts (Costanza et al., 1993). In this philosophy the basis for an ecological restoration plan for the Schelde estuary was drawn, aimed at optimisation of physical, chemical and ecological processes and with consideration for its other societal functions (Van den Bergh et al., 2003). Critical sites for the enhancement of these processes should be identified on a landscape level, with the help of land-use decision tools. Finally public involvement should be improved and reach beyond viewpoints and preferences of interest groups, which dominated the discussions so far. A starting point could be to obtain a wider perspective of citizen preferences through surveys and the development of choice behaviour models (Pouta et al., 2000).

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