# ANNUAL REPORT ANT SMELT 2010:

A changing role for smelt *Osmerus eperlanus* in the Lake IJsselmeer and Lake Markermeer foodweb? Climate- and nutrient-induced changes in ecosystem functioning.

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# INHOUDSOPGAVE

# A changing role for smelt *Osmerus eperlanus* in the Lake IJsselmeer and Lake Markermeer foodweb? Climate- and nutrient-induced changes in ecosystem functioning.

## INTRODUCTION

The smelt project is part of a larger research project that aims at generating, exploring and testing different possible explanations for the observed Autonomous Negative Trends (ANT) in water fowl in Lake Markermeer and Lake IJsselmeer. The smelt populations in both lakes have been in severe decline since 1990. These declines have a large impact on the conservation of water birds relying on smelt as their prey and the fishery both on smelt and on piscivorous fish relying on smelt. In winter time the Lake IJsselmeer area is home to the largest population of waterfowl in Western Europe. The area is therefore considered to be an important Natura-2000 area. Identification of the causes of the observed negative trends will help managers (RWS) to take the appropriate restoration measures and thereby improve the these lakes as habitat for waterfowl.

In particular, we aim at estimating the relative sensitivity of this key (fish) species to manageable and unmanageable drivers such as fisheries, nutrient load and climate change. The smelt sub-project specifically aims at translating the scientific conclusions into management options to improve conditions for the smelt population of Lake IJsselmeer and Lake Markermeer, thereby fulfilling the new Natura2000 guidelines stipulated by the EU.

Several hypotheses have been formulated that could explain the decline of the land-locked smelt populations in both lakes. These include reduced primary and secondary production through changes in nutrient load, reduced feeding efficiency because of increased water transparency, increased summer mortality due to high temperatures and low oxygen concentrations, reduced reproduction caused by high metabolism combined with low food during warm winters, and various changes in the interactions between smelt and its main predator, pikeperch.

In shallow lakes, smelt perform low-amplitude vertical migrations (Piersma et al. 1988), which may cause variation in food availability for ”shearing” piscivorous birds (terns) as they only have access to the first 0.5 m of water. Prey fish, like smelt, must trade off foraging efficiency against predation risk from above (piscivorous birds) and below (perch, pikeperch). Smelt concentrates near the surface when the water is turbid (Secchi depth = 0.5m) and near the bottom with clearer water (Secchi depth = 1.2m). Increased water transparency, due to for example reduced nutrient loading, may reduce the food availability for “shearing” fish eating birds if prey (smelt) stay near the bottom.

Because of a drop in phosphate levels around the 1980s, right around the time lake Markermeer was formed, a high abundance of small-sized fish was reinforced by the strong growing overfishing on piscivorous fish like perch and pikeperch. However, this did not necessarily increase the food availability for piscivorous bird species. It was suggested that there is a complex interaction between piscivorous birds and (pike)perch (de Leeuw 2001). Smelt schools, being hunted by perch and pike perch, are chased to the surface where they are awaited by piscivorous birds (Tulp and De Leeuw 2002).

Climate change in the lakes have likely had a significant impact on smelt populations. The number of days with water temperatures over 20°C has increased since the 1990s, which could have caused increased mortality for a cold water species like smelt. Dissolved oxygen decreases with increasing water temperatures which may enhance mortality during the summer months. This leaves less individuals for the migrating bird species that rely on smelt as a food source, but also decreases the number of individuals left for the next spawning round.

The objective of this project is to unravel the mechanisms underlying the decline of smelt, a combination of field work and laboratory experiments will be carried out and population models will be used to assess the impact of possible cumulative and interactive processes. The project will be carried out in the broader context of the ANT project, and specifically aim at translating the scientific conclusions into management options to improve conditions for the smelt population of IJsselmeer and Markermeer.

## HYPOTHESES

Hypothesized mechanisms, as formulated in the approved Research Proposal, for the observed declines of the land-locked smelt populations in Lake IJsselmeer and Lake Markermeer are:

**Nutrients:**

1) Reduced primary (algae) and secondary (zooplankton) production through changes in nutrient loads (P/N) negatively affect food conditions of smelt.

**Climate:**

2) Mortality in summer increased due to to high water temperatures and low oxygen concentrations.
3) Fecundity reduced in warmer winters (high food demands at low food production rates) when gonads might be used as an energy source.
4) Changes in water temperature have caused a mismatch between larval development and prey availability.

**Predation pressure by piscivorous fish:**

5) Increased water transparency and schooling behaviour incur temporarily high densities which can be exploited efficiently.
6) Predation windows by young perch and pikeperch are advanced in warmer springs.
7) Benthivorous ruffe population increased incurring a higher predation pressure on smelt eggs.

**Water transparency**

8) Feeding efficiency of the zooplanktivorous smelt is reduced because of increased (periods of high) water transparency.

**Increased toxicity**

9) Increased toxicity (microcystines, discharged toxic substances) decrease smelt survival (or food conditions)

The following chapters provide some background information for most of the Hypotheses described above. Furthermore some of the preliminary results from 2010 are presented in these chapters.

## GROWTH

One of the more intriguing aspects of the life-history of the land-locked smelt populations in Lake IJsselmeer and Lake Markermeer is the short life span (1-2 years). Both diadromous and land-locked smelt populations in other areas live considerably longer (4-8 years) and appear to grow faster, reaching larger maximum sizes (Fig. 1). However, the commercial catch of Lake Peipsi, a similar shallow lake like Lake IJsselmeer, consisted of just two year classes, 83% 1 year old and 17% two year old smelt. With respect to age it has to be noted that smelt in Lake IJsselmeer and Lake Markermeer have never been properly aged. Ageing will be conducted in 2011 to provide an accurate description of growth and the age structure of the smelt populations in both lakes.

One explanation of the lack of large/old smelt is the high (avian) predation pressure on smelt. Van Eerden et al. (1993) suggested that the disappearance of the $1^+$ cohort in the autumn was due to avian predation (Fig. 2). Growth data from 2010 show a clear presence of two cohorts during the summer. In September the cohorts start to 'fuse' but the older cohort has not disappeared (yet?).

An alternative explanation for the lack of larger/older smelt could be a bottleneck in (pelagic) macro-fauna like *Chaoborus* and *Neomysis* for larger smelt (see Section 6.1). It would be interesting to know if common mechanisms regulate the short life span of land-locked smelt in large lakes like Lake IJsselmeer and Lake Peipsi.

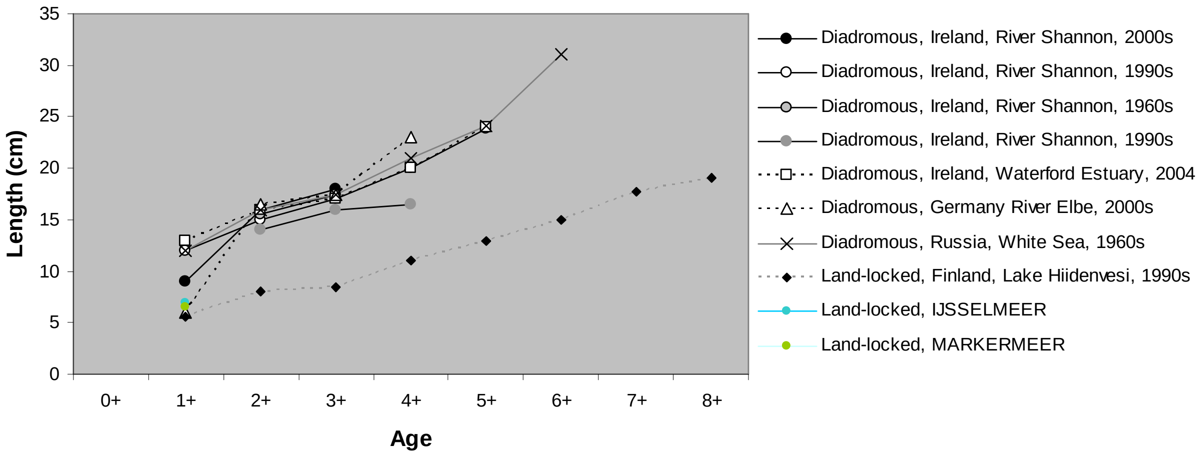


**Fig. 1:** Growth of diadromous and land-locked smelt populations throughout its natural range (Quigley et al (2004), Doherty (1999), Bracken and Kennedy (1967),Geragthy (1996), Doherty and McCarthy (2004), Scholle (2007),Vinni et al. (2004).

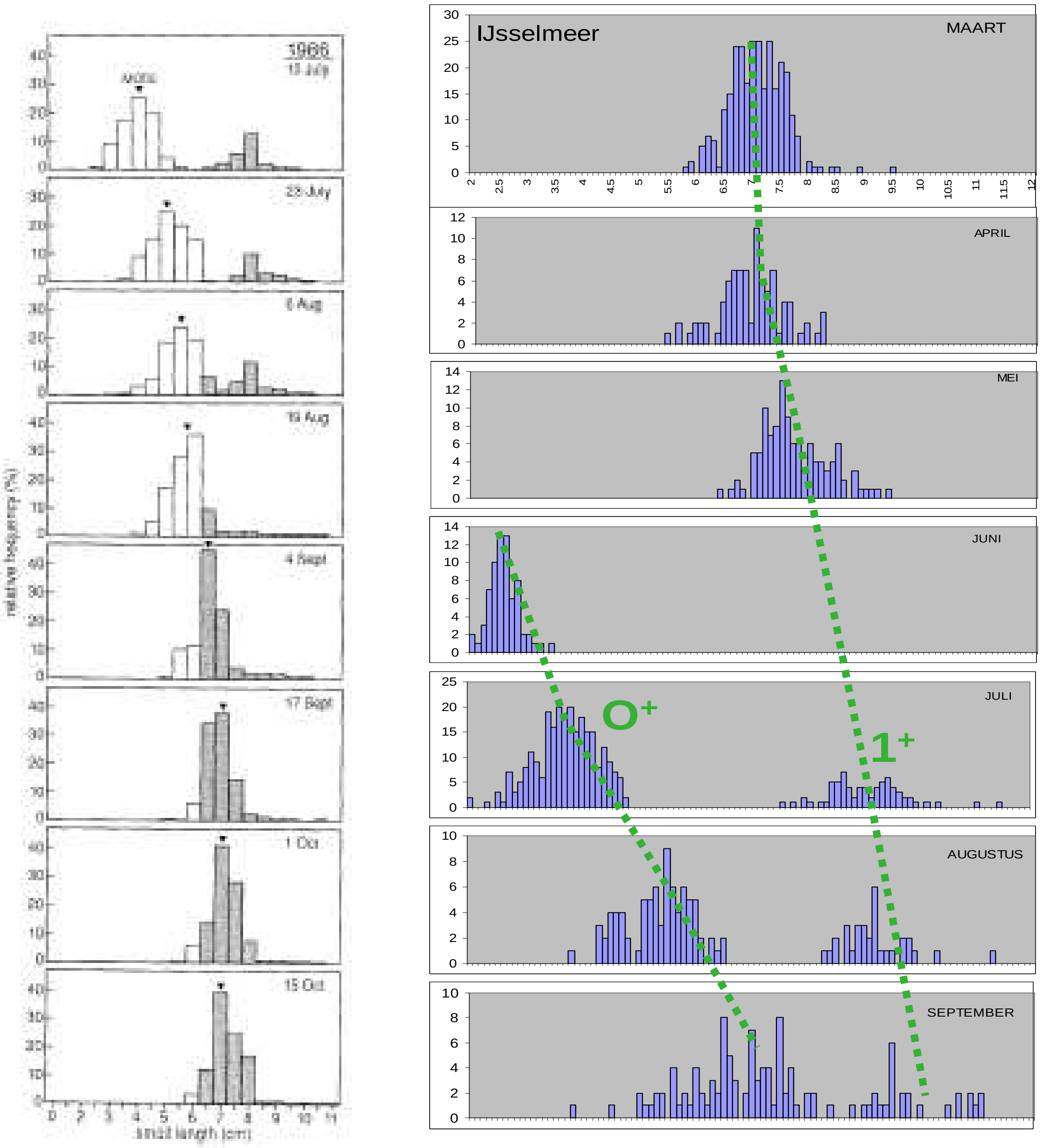


**Fig 2:** Left: Growth of smelt in the Vrouwenzand area during the 1986 season. The occurrence of smelt longer than 6.5 cm which are of special importance to the grebes according to Van Eerden et al. (1993) is shown by *shaded bars.* Note the disappearance of the 1 + cohort during the course of August, which is probably due to avian predation (Van Eerden et al. 1993). Right: Growth of smelt in Lake IJsselmeer in 2010.

# WATER TEMPERATURE

Water temperature can strongly influence growth rate and mortality of fish (Jobling, 2002). Smelt is generally considered to be a cold water species (Nellbring, 1989) and has been shown to react distinctly to temperature fluctuations outside the optimal ranges. Two examples of a negative correlation between abundance of smelt and water temperature are shown in Fig. 3. Mean water temperature in Lake IJsselmeer (Fig. 4) and Lake Markermeer have increased over the past decades. It is therefore likely that, especially if current trends persist, Lake IJsselmeer and Lake Markermeer may become unsuitable for smelt. Temperature-induced mortality can occur in summer and winter as described above in Section 2 Hypotheses Climate.

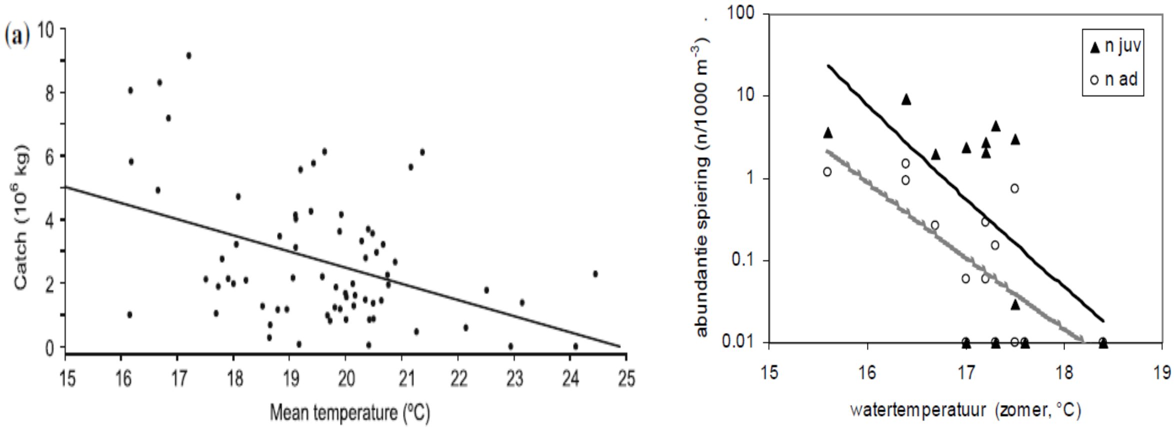


**Fig. 3:** Left: The dependence of catches of smelt on mean water temperature on days 166–200 of the previous years (Kangur et al 2007). Right: Abundance of smelt in the first (juvenile) and second (from juvenile to adult stage) growth season in the Gironde River, France (Pronier and Rochard 1998).

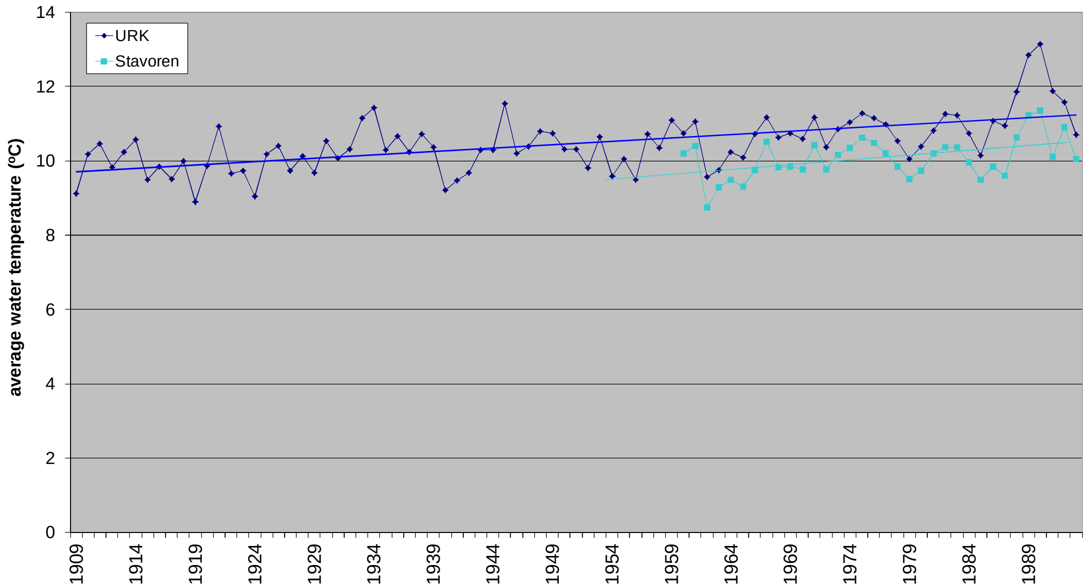


**Fig. 4:** Changes in average annual water temperature at two locations in Lake IJsselmeer.

# MIGRATION

## CONNECTIVITY LAND-LOCKED AND DIADROMOUS POPULATIONS

An important question in understanding the population dynamics of smelt is the connectivity between the anadromous smelt and the landlocked smelt populations in Lake IJsselmeer and Lake Markermeer. What is the contribution of anadromous smelt to the total spawning biomass of smelt in LakeIJsselmeer and Markermeer?

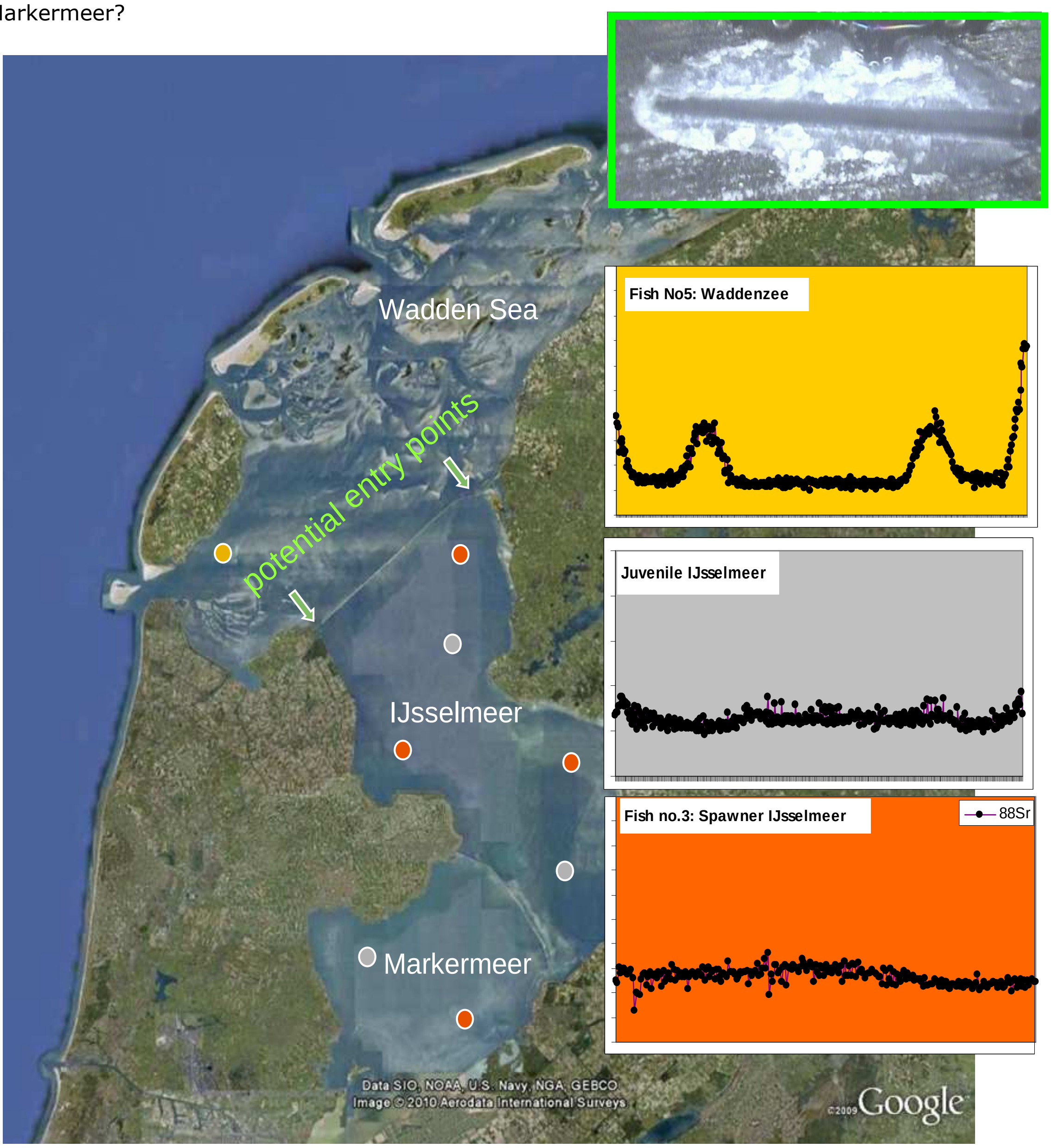


**Fig. 5:** Dots indicate the locations were smelt were collected for microchemistry analysis of the otoliths to determine their migratory history between fresh water and marine environments. Smelt collected in the Wadden Sea (top graph) show movement between freshwater (low Sr concentrations) and sea water (high Sr concentrations). The low Sr concentrations in the otoliths of juvenile smelt and adult spawning smelt from Lake IJsselmeer indicate a freshwater history.

Recently RWS has investigated the possibilities of adjusting the management of the sluices in the Aflsluitdijk to improve the immigration of especially smelt and other diadromous fish species. Could the land-locked smelt stock be resupplied with the anadromous stock?

It is important to determine the current contribution of diadromous smelt to the total spawning biomass. With the use of microchemistry analyses (calcium and strontium) of otoliths we have investigated the migratory history between marine and fresh water (Borcherding et al. 2008) of smelt collected at different places in IJsselmeer and Markermeer. Insight in the relative importance of the marine stock for the landlocked stock is crucial to understand the population dynamics.

Microchemistry analyses of otoliths has been carried out in 2010 to determine if individual smelt have remained in fresh water, marine water or both. Three groups of smelt were collected for otolith analysis: 25 adult smelt from the Wadden Sea, 100 adult spawners from severeal locations in Lake IJsselmeer and 20 juvenile ($0^+$) smelt from Lake IJsselmeer. The results so far indicate that the contribution of migrating smelt from the Waddens Sea to the spawning population in Lake IJsselmeer is negligible. Adult smelt from the Wadden Sea clearly demonstrated the diadromous nature of smelt with several periods of habitation of fresh and marine environments (Fig. 5). At present the Afsluitdijk forms a substantial barrier, preventing mature smelt from the Wadden Sea to migrate to Lake IJsselmeer to spawn. The implementation of fish-friendly sluice management of the Afsluitdijk could potentially improve the spawning populations of smelt in Lake IJsselmeer.

A population genetic study will hopefully start in 2011 in collaboration with scientists from Belgium to determine if the smelt that aggregate before the Afsluitdijk each spring originate from Lake IJsselmeer (homing).

## VERTICAL MIGRATION IN THE WATER COLUMN

Water transparency has a pronounced effect on the vertical distribution pattern (VDP) of smelt. In IJsselmeer, Mous et al. (2004) found that smelt stayed near the surface in turbid water (EXT -2.8$m^{-1}$; Secchi depth 0.5m) and was observed near the bottom in clearer water (EXT -1.4$m^{-1}$; Secchi depth 1.1m). In Lake IJsselmeer smelt was found higher in the water column than was to be expected based on light intensity. These authors further suggested that low water transparency overruled light sensitivity.

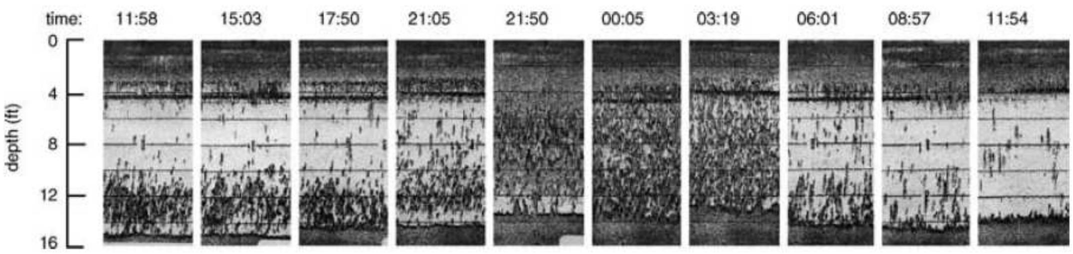


**Fig 6:** Hydroacoustic recordings of smelt in Lake IJsselmeer (subset 22:00h, sunrise 5:15h). Fish were more dispersed over the water column during night-time than during the day-time (Mous et al. 2004).

The diel changes in VDP (Fig. 6, Mous et al 2004) were also observed by Piersma et al. (1988). During the day (and possibly during the night) smelt live in schools, a mechanism to reduce predation. When smelt forage in the twilight periods (Table 1), schools might break up and smelt probably move more independently to enable their (visual) foraging on zooplankton.

# SMELT AS PREDATOR

## ONTOGENETIC DIET SHIFTS AND DIEL FEEDING PATTERNS

Smelt is predominantly a zooplanktivorous species at younger ages but during ontogeny gradually shifts to larger prey items like macro-invertebrates (*Chaoborus*, insects, *Mysis*) and the largest individuals are piscivorous (Fig. 7, 8). Diel patterns in feeding activity were clearly demonstrated by Vinni et al. (2005), with highest feeding activity occurring in the (evening) twilight.

**Table 1:** Diel and size-related (total length) variations in frequency of empty stomachs (FES) of smelt (Vinni et al. 2005).

| | | **Total Length (cm)** | | | | | |
|---|---|---|---|---|---|---|---|
| | **Mean FES** | **<7.0** | **7.0-7.9** | **8.0-8.9** | **9.0-9.9** | **>10.0** | **Total n** |
| **Day** | 17.1 | 16.3 | 9.9 | 25.5 | 6.0 | 22.6 | 544 |
| ***Evening*** | *7.5* | *9.0* | *0.0* | *7.1* | *8.5* | *26.7* | 467 |
| **Night** | 23.5 | 23.9 | 14.8 | 23.1 | 29.0 | 66.7 | 400 |
| **Morning** | 20.3 | 18.8 | 18.0 | 21.6 | 10.5 | 45.5 | 479 |

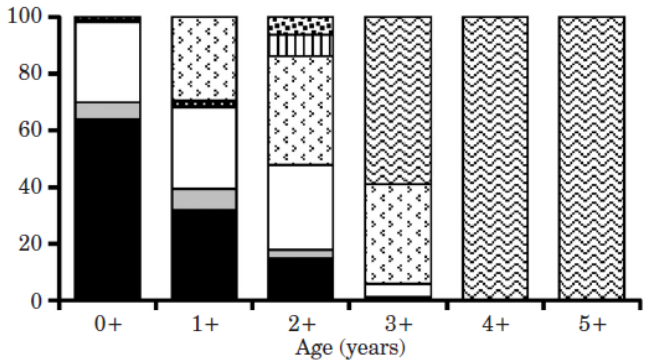


**Fig. 7:** Diet composition of smelt in the eutrophic Lake Hiidenvesi, Finnland (black = Copepoda, grey = *Bosmina*, white = *Daphnia*, black with small white dots = *Cladocera* spp., > < = *Chaoborus flavicans*, vertical bar = *Mysis relicta*, waves = smelt (Vinni et al. 2004).

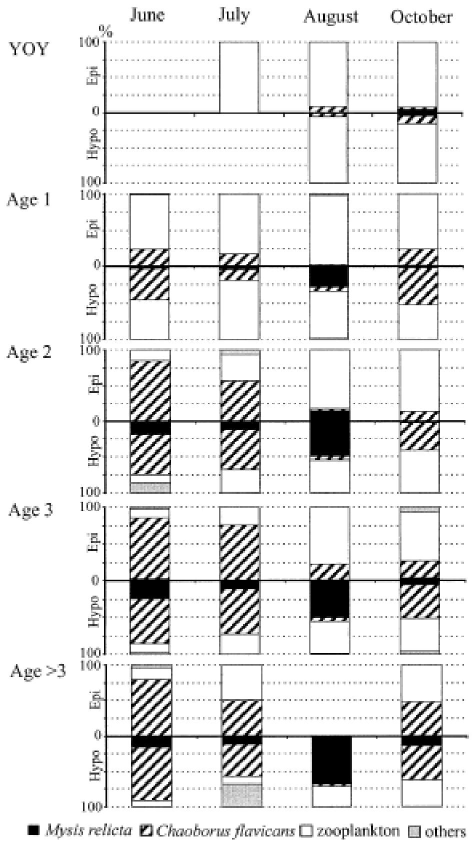


**Fig. 8.** The food composition of the different smelt age groups in the hypolimnion and in the epilimnion in June, July, August, and October 1999 (Horppila et al 2003).

Preliminary diet data of smelt captured in Lake Markermeer and Lake IJsselmeer are presented in Fig. 9. Surprisingly, in March 2010 the benthic Gammeridae formed a significant part of the diet of smelt. In April smelt shifted to pelagic copepods.

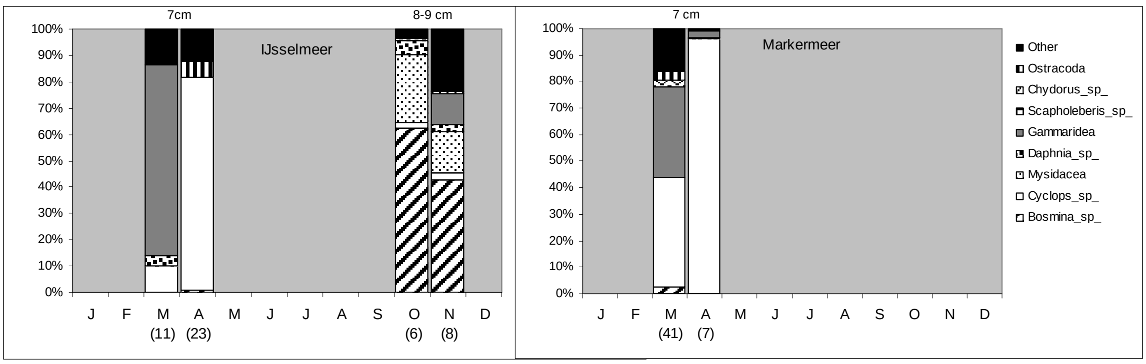


**Fig. 9:** Preliminary diet data of smelt in IJsselmeer and Markermeer. Sample sizes are indicated below the bars.

## PREY SELECTION

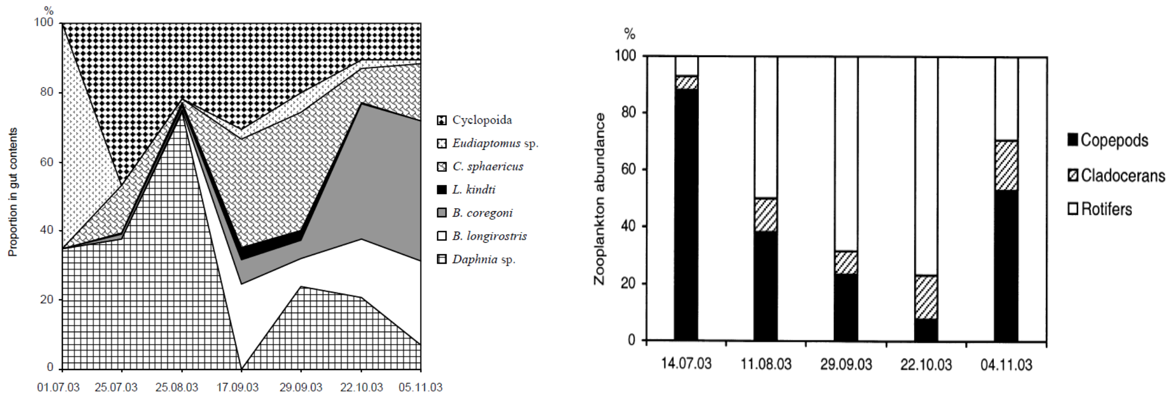


**Fig. 10:** Comparison of zooplankton composition in the diet of smelt [left] and in the environment [right] in Lake Peipsi (data from Salujõe et al. 2008).

Salujõe et al. (2008) found that in Lake Peipsi smelt prefer Cladocerans over other zooplankton. While Cladocerans formed only a minor part (~10%) of the zooplankton community (Fig. 10, right), the proportion of Cladocerans in the diet of smelt was significantly higher (>50%). A possible reason for the preference of cladocerans is the higher food quality (lower c:p ratio) compared with copepods. An alternative explanation might be that it is easier to catch cladocerans.

## FEEDING EFFICIENCY

The effects of turbidity on the feeding efficiency of planktivorous fish have been frequently studied. Feeding efficiency is usually reduced with increasing water turbidity (Fig. 11; Vinyard and O'Brien 1976; Bruton 1985). This is because most planktivorous fish depend on their vision in prey detection, and increasing turbidity decreases their reactive distance. However, the feeding efficiency of fish does not always decline constantly with increasing turbidity. Some studies have shown that moderate turbidity values (up to 20–30 NTU) may enhance the feeding success of planktivores foraging on transparent prey by providing contrast between the background and the prey (Boehlert and Morgan 1985; Utne-Palm 1999; Horppila et al. 2004).

In Lake IJsselmeer and Lake Markermeer no obvious changes in vertical transparency have occurred since the 1970s (Fig 12). Changes in transparency and related changes in feeding efficiency and/or predation risk (Hypotheses 4 and 7 in Section 2) do not seem to be relevant as a cause for the decline in smelt.

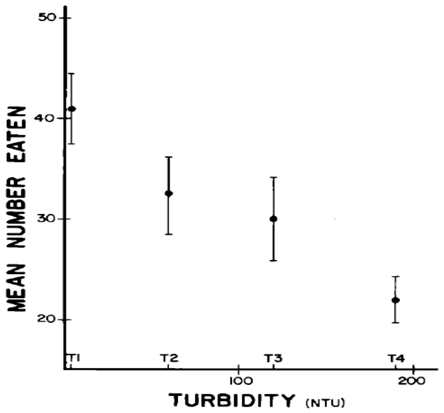


**Fig. 11**: Effect of turbidity (nephelometric turbidity units, NTU) on the total number of Daphnia eaten per fish (bluegill) during 3 minutes. Each point represents the mean of seven replicates (± 1 SE) except that for the 60-NTU treatment T2, which is the mean of four replicates (Gardner, 1981).

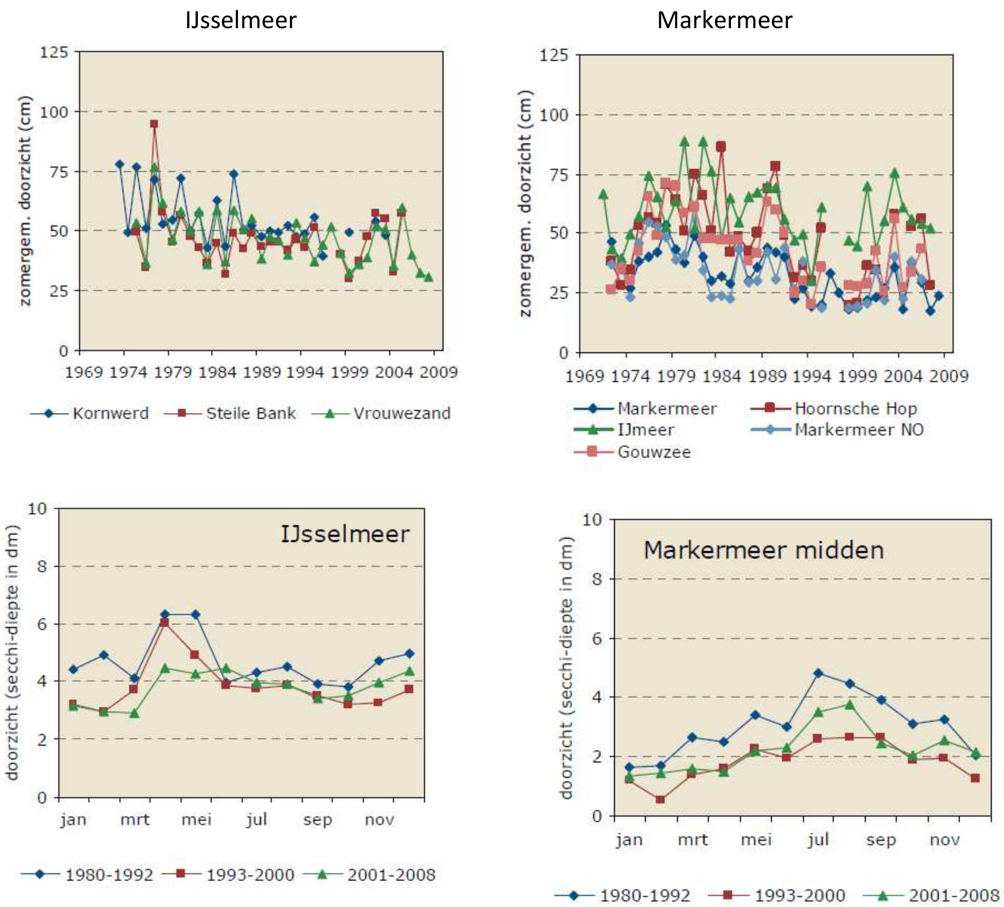


**Fig. 12:** Historical changes in transparency in Lake IJsselmeer and Lake Markermeer (Noordhuis 2010).

# SMELT AS PREY

## AVIAN PREDATION

Smelt is a key prey species for many species of waterbirds such as grebes, mergansers and black terns (Fig. 13). Unfortunately most diet data wers collected in the 1980s before the major changes occurred in Lake IJsselmeer and Lake Markermeer. Recent diet data of water birds is urgently required and only available for Cormorants and Black Tern. The small-sized smelt does not appear to be an important prey items for (adult) cormorants ( Fig. 14).

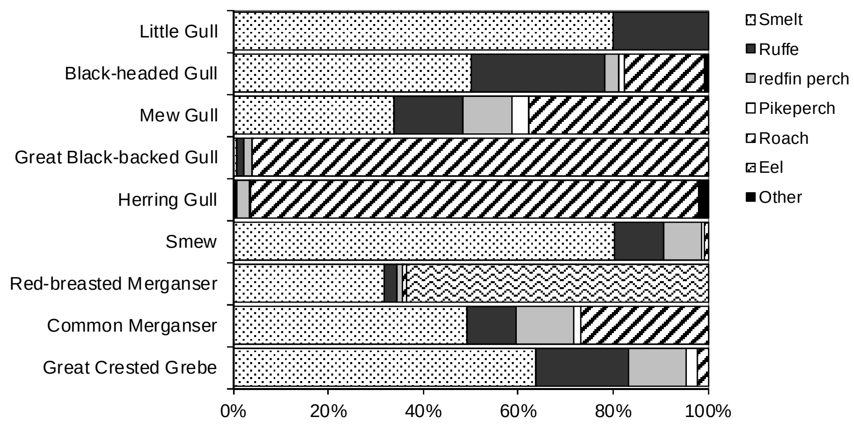


**Fig. 13 :** Fish species composition (%) in the diet of piscivorous birds in the 1980s. Sources: Platteeuw (1985), Beekman & Platteeuw (1984), Voslamber (1991), Piersma et al. (1997). Diet constructed from stomach contents and/or pellets.

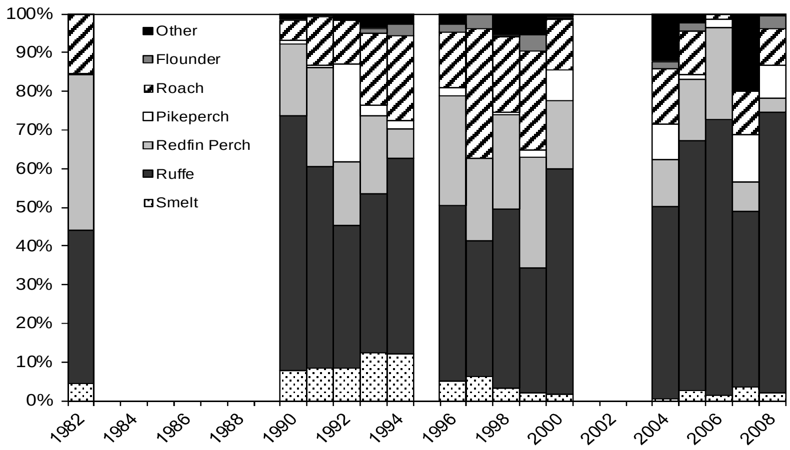


**Fig. 14**: Fish species composition (%) in the diet of cormorants in the Oostvaardersplassen (Noordhuis 2010).

In Lake IJsselmeer diving birds like grebes feed on smelt during twilight when smelt are feeding themselves and schools break up. On the other hand, shearing (shallow diving) birds like terns feed during most of the daylight period (Figs. 16, 17). Predation success by shallow diving birds is dependent on transparency (Fig. 18). The relationship is non-linear. If transparency is too low predation success decreases because prey fish can no longer be detected. If transparency is high, fish schools are found deeper in the water column, reducing capture success of shallow diving birds.

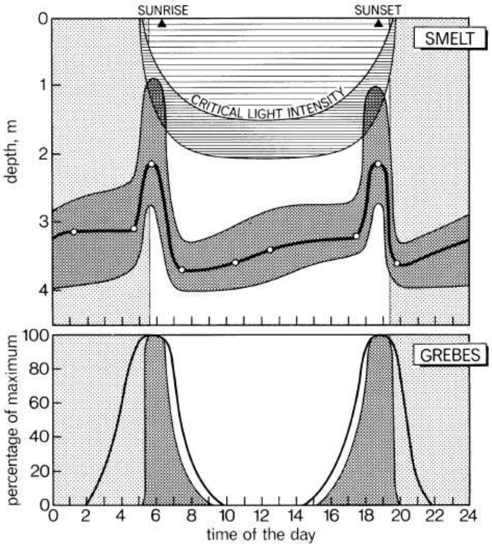


**Fig. 15.** Summary of the diel changes in the vertical distribution of smelt and the depths of which critical light intensities reach (top) and in the feeding activity of great crested grebes (bottom)(Piersma et al 1988).

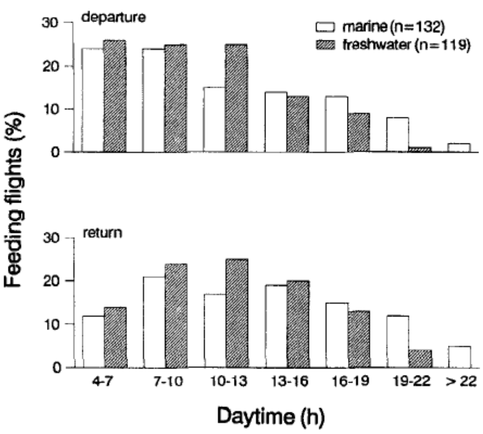


**Fig 16:** Terns feeding in freshwater and at sea. Times of feeding trip departures and returns of Common Tern (Becker et al 1997).

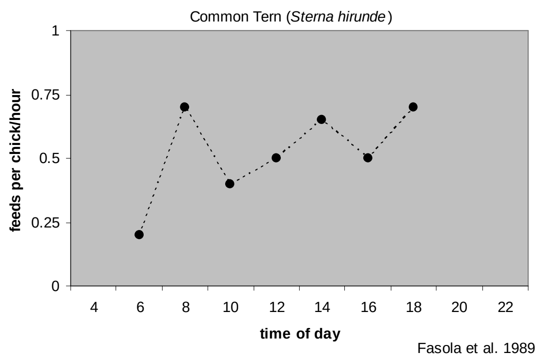


**Fig 17:** Daily rhythms of arrivals at the nests by adult Common Tern with food for chicks. (Fasola et al 1989).

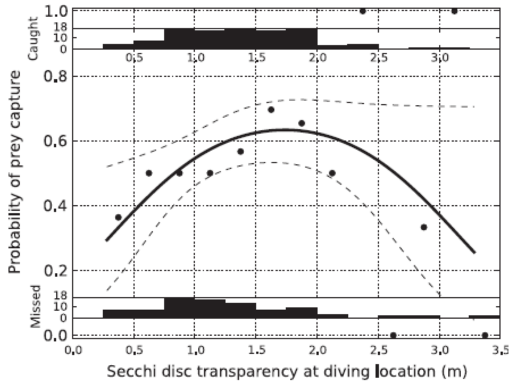


**Fig 18:** Relationship between transparency and prey capture probability for sandwich tern. The solid line presents the results of the logistic regression, the dotted lines give the 95% confidence intervals, the histograms on the top and bottom give, respectively, the number of caught prey and missed prey and the dots give the prey capture probability for each histogram class (Baptist and Leopold 2010).

## TELEOST PREDATION

Smelt is the main prey item of both (small <20cm TL) pikeperch and perch in Lake IJsselmeer (Buijse 1992). In both species the onset of piscivory during ontogeny means the onset of eating $0^+$ smelt (Fig. 19). As with the diet data of piscivorous birds, the diet data of piscivorous fish dates from the mid-1980s and 1990s before some of the declines in waterfowl and smelt occurred in IJsselmeer and Markermeer. The importance of smelt as prey may have changed over the past decade(s) as illustrated by recent diet data of adult pikeperch in Lake IJsselmeer and Lake Markermeer (Fig. 20) in comparison with earlier data (Fig. 21). A study of current diets of smelt, its competitors (ruffe, juvenile perch, roach) and its avian and teleost predators is also important for the cluster System Analysis within ANT.

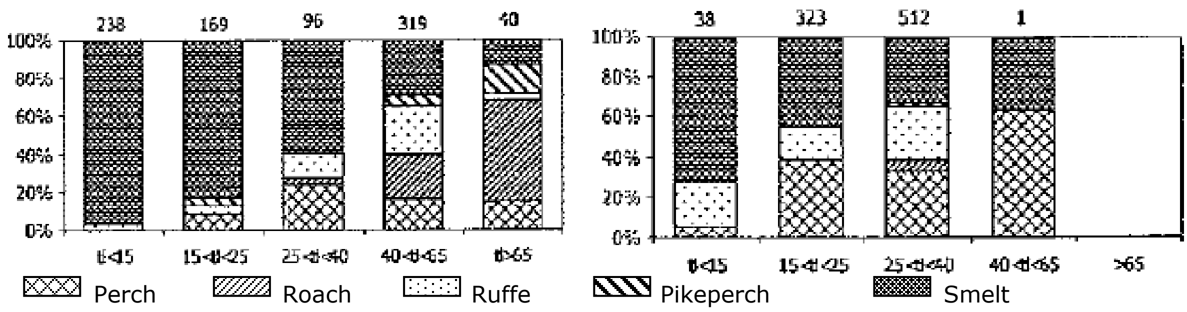


**Fig. 19.** Ontogenetic diet shifts of pikeperch (left) and perch (right) from Lake IJsselmeer (Rabaey, 2001). Sample sizes are indicated above the bars.

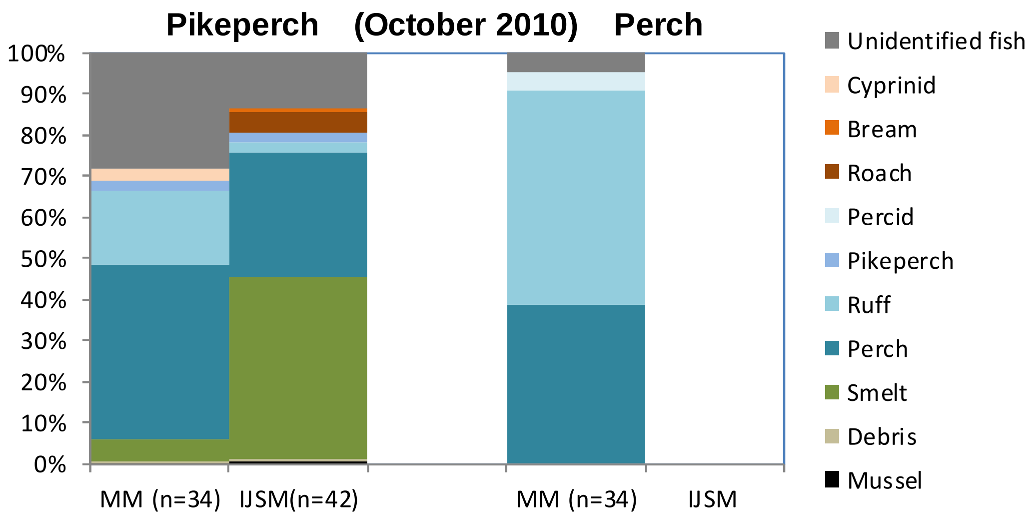


**Fig. 20.** Prey species composition of adult pikeperch (40-50 cm TL) and perch (25-40 cm TL) in Markermeer (MM) and IJsselmeer (IJSM). Sample sizes are indicated below the bars.

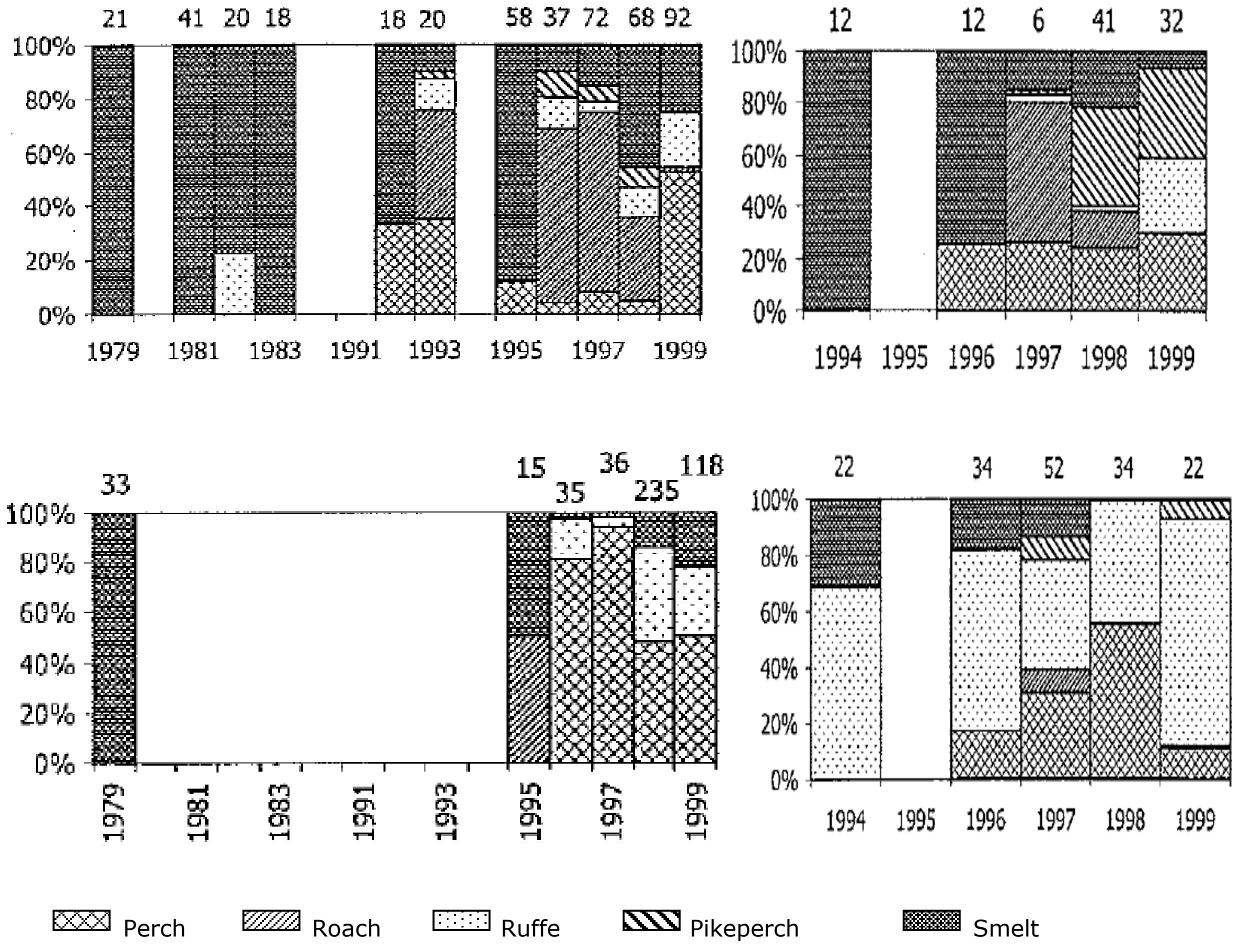


**Fig. 21.** Diet of pikeperch (top) and Perch in OCT-NOV in Lake IJsselmeer (left) and Lake Markermeer (right) (Rabaey 2001). Sample size are indicated above the bars.

## FISHERIES

Smelt is not produced for the domestic market but the whole catch is exported, especially to Mediterranean countries. Since the 1980s landings (Fig. 22 top) from IJsselmeer and Markermeer have been dominated by smelt (in tonnage not value). In the last decade the smelt fisheries has been closed 5 years due to low stock levels (Fig. 21 middle and bottom). Care has to be taken with the interpretation of the landing statistics from the auction because not all fish is sold through the auction  and some of the fish sold in the auction might be caught in other waters than IJsselmeer/Markermeer.

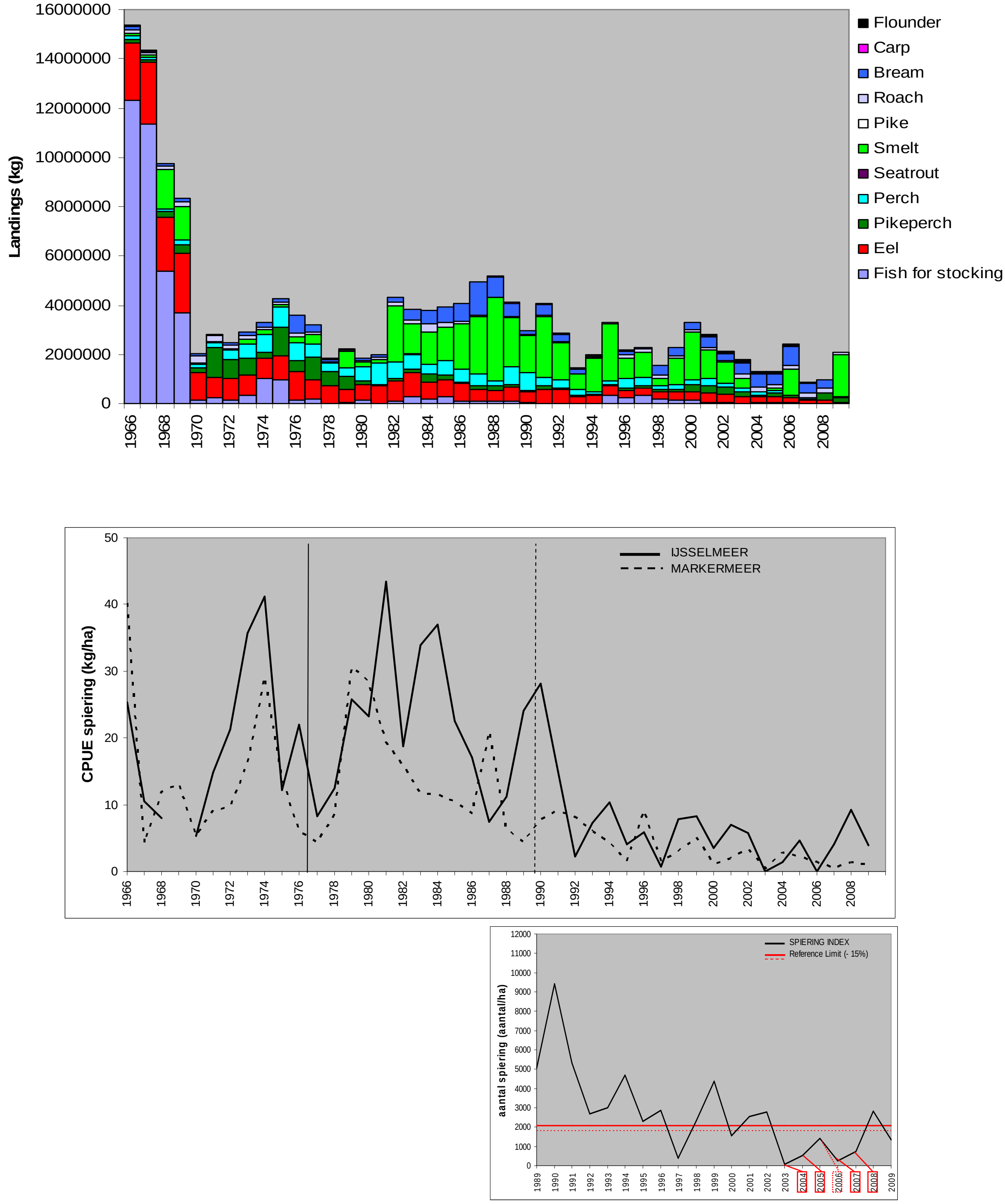


**Fig. 21.** (top) Landings of fish species from Lake IJsselmeer and Lake Markermeer as provided by Productschap Vis. (middle) Changes in smelt abundance in Lake IJsselmeer and Lake Markermeer based on (standardized since 1989) trawl surveys. (bottom) Development of the Smelt Index used by the Ministry of Economy, Agriculture and Innovation to assist in the decision to open or close the smelt fisheries in spring. Note that in 2004, 2005, 2007, 2008 and 2010 the fishery was closed, in 2006 the season was shortened and started later.

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# KWALITEITSBORGING:

IMARES beschikt over een ISO 9001:2008 gecertificeerd kwaliteitsmanagementsysteem (certificaatnummer: 57846-2009-AQ-NLD-RvA). Dit certificaat is geldig tot 15 december 2012. De organisatie is gecertificeerd sinds 27 februari 2001. De certificering is uitgevoerd door DNV Certification B.V. Het laatste controlebezoek vond plaats op 22-24 april 2009. Daarnaast beschikt het chemisch laboratorium van de afdeling Milieu over een NEN-EN-ISO/IEC 17025:2005 accreditatie voor testlaboratoria met nummer L097. Deze accreditatie is geldig tot 27 maart 2013 en is voor het eerst verleend op 27 maart 1997; deze accreditatie is verleend door de Raad voor Accreditatie.

# VERANTWOORDING

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Projectnummer: 4302100501

Dit rapport is met grote zorgvuldigheid tot stand gekomen. De wetenschappelijke kwaliteit is intern getoetst door een collega-onderzoeker en het betreffende afdelingshoofd van IMARES.

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