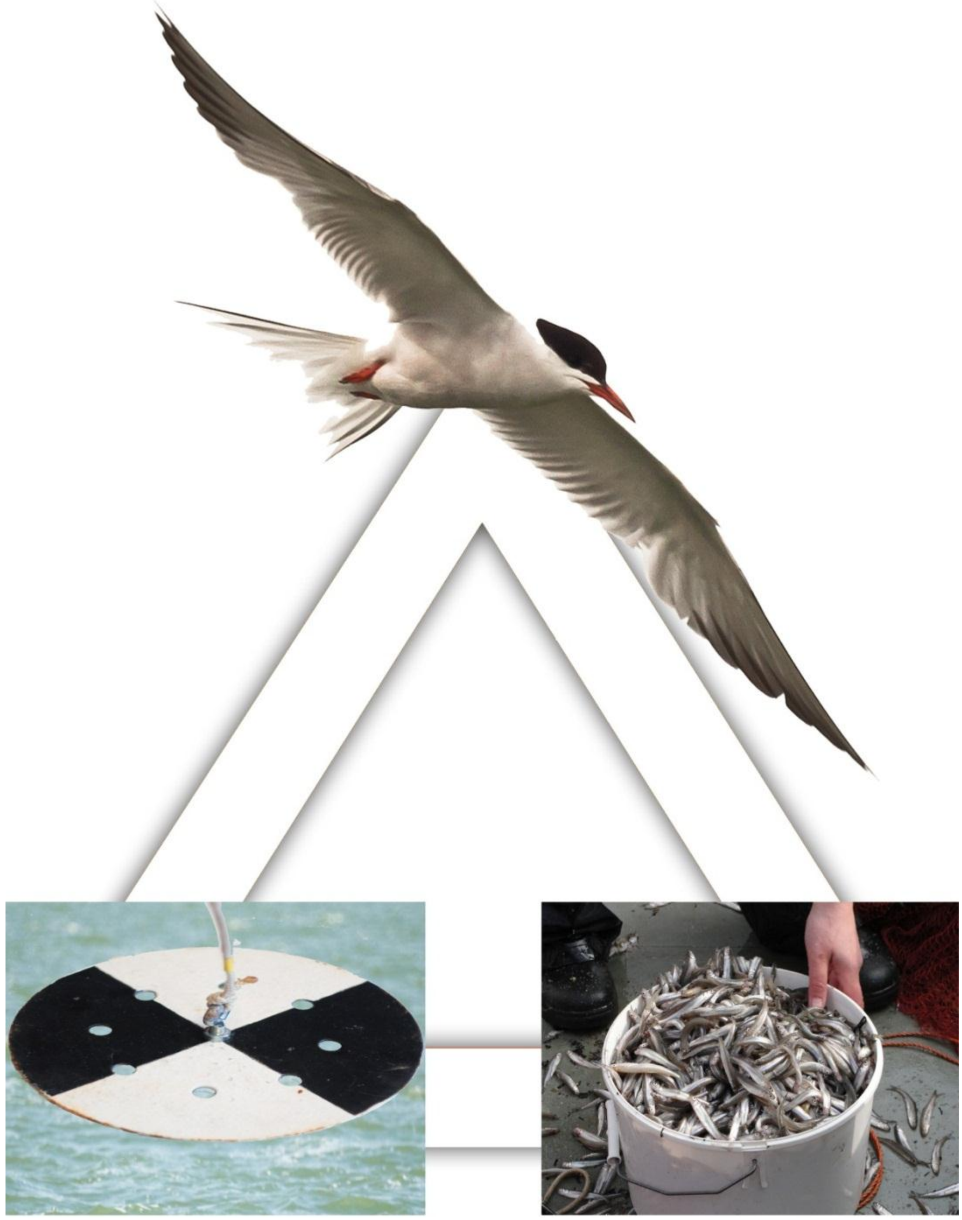
Our common tern in Lake IJsselmeer

Relation between common tern, smelt abundance and transparency in the Lake IJsselmeer area



M.Sc Thesis

P. van de Ven

March 2012

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Aquatic Ecology and Water Quality Management Group
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Preface

This report is the result of a thesis research from March 2011 till March 2012 from the Wageningen University, Aquatic Ecology and Water Quality Management Group. This research is aimed at the relation between common tern, smelt and transparency in the Lake IJsselmeer area. The research is placed under the project ANT (Autonome Neergaande Trends).

This report would not have been possible without the support and help of several people, whom I want to thank for it. First of all I want to thank Stef van Rijn, my supervisor from Rijkswaterstaat. His knowledge provided me with new insights and his never fading enthusiasm inspired me enormously. Second, I want to thank Edwin Peeters, my supervisor from Wageningen. He helped me with the structure and the statistical part of this report. Next I thank Ruurd Noordhuis from Deltares for providing me background information for my report and joining me on the second 24-hour measurement. Furthermore I want to thank Marieke Keller (Imares) for helping me with determining the stomach content of ruffe, providing me with the fish and transparency data of Lake IJsselmeer and Lake Markermeer and companionship during both 24-hour measurements. Jochem 't Hoen for providing some extra literature and company on the second 24-hour measurement. Olga Haenen and Pieke Molenaar for providing information about the stomach content of ruffe and taking some time for me to look at my pictures. Martin Lips and Paul Ruiter for arranging the enormous amount of fish data in Excel using programming skills. Lastly I want to thank Frank van Oosterhout (WUR) and Femke van Beersum. Not for any contribution to the report but more for the enthusiasm and company they gave me during the writing of this report.

Wageningen, March 2012

Phillip van de Ven

Abstract

Since 1980, piscivorous bird numbers were decreasing in the Lake IJsselmeer area. This area is of importance for all kinds of birds and therefore designated as a Natura2000 area. The project ANT (Autonome Neergaande Trends) started to research these negative trends in the area. This study focuses on the ANT species common tern (*Sterna hirundo*). The population of this bird increased enormously after the creation of nature island De Kreupel in 2003. From 2009 on breeding success became poor. It is believed that the stock of 1+ smelt (*Osmerus eperlanus*), an important fish for the common tern and their young, was too low for the common tern to feed their young. Smelt is the key species in the ecosystem of the Lake IJsselmeer and the relation of common tern with smelt is very important for a successful breeding success. The following aspects were studied for the year 2010 and 2011:

- The diet of the common tern and the cormorant (*Phalacrocorax carbo*)
- The proportion of 1+ smelt in the diet of the common tern in July, August and September
- The diet of the common tern, cormorant and catches with boat hauls were compared to each other to find differences in proportion of 0+ and 1+ smelt.
- The vertical distribution pattern of fish during 24 hours. Fish distributes more evenly in the water column around sundown and sunset and the common tern could use these times to forage.
- The influence of transparency on smelt or common tern
- The effect of ruffe predation on smelt eggs for the stock of smelt later in the season.

The diet of the common tern did not differ in total weight in the studied months (Kruskal-Wallis test=8.619, df=5 and p=0.125). In 2011 less fish was caught, but the species composition differed, especially in July. The amount of perch caught in July 2011 added 23% to the total weight of fish in the pellet, while in 2010 perch only contributed 3% of the weight.
For both years the highest amount of smelt was caught in July. Of the 5.5 smelt per pellet in the diet (85%) in 2010, 3.6 smelt (65%) was considered 1+. Also in July 2011, when 2.9 smelt per pellet (71%) was caught, 1.8 (61%) was 1+ smelt. In August and September proportion of other fish increased. The smelt proportion decreased to 45% in 2010, 33% in September 2010 and 63% in August 2011. The influx of the 0+ (young-of-the-year) smelt and only 20% of the total smelt found in the pellet was considered 1+. Still, even in low numbers 1+ smelt contributed mostly to the weight proportion of the total smelt. While in July 2010 and 2011 1+ smelt contributed more than 90% of the total weight, in August this only slightly decreased (when compared to the number of smelt caught) to 70-75% and 60% in September.
With these high values in weight proportion 1+ smelt is very important for the common tern. This is especially in July, when the common tern still has fledglings which need to be fed with high quality food. Later the importance of 1+ smelt becomes somewhat less with the influx of 0+ smelt and other fish species.

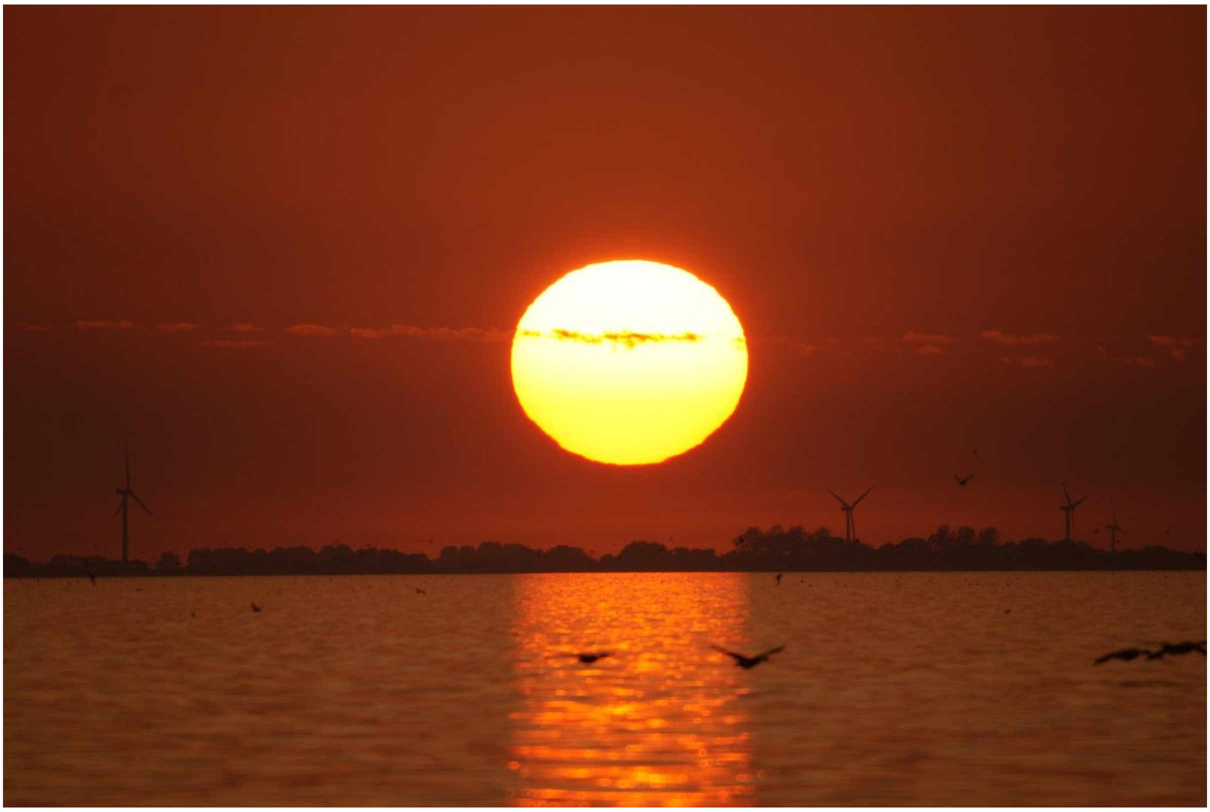
The boat hauls show that for both Lake IJsselmeer and Lake Markermeer 1+ proportion of smelt is minimized (less than 10%) with the influx of 0+ smelt. Influx of 0+ smelt was in June 2010 and July 2011. In 2010 most smelt was caught in Lake IJsselmeer, in 2011 most smelt was caught in Lake Markermeer. This did not affect the common tern as less fish, but with higher weight was caught. Also forage flights from De Kreupel to Lake Markermeer were observed. Probably conditions for foraging were more suitable on Lake Markermeer than on Lake IJsselmeer. The low numbers of 1+ smelt in the boat catches and the relatively high numbers of 1+ smelt found in the diet of the common tern further proofs that 1+ smelt is important for the common tern.

From a study in 1988 it was shown that smelt distributed more evenly in the water column during sundown and sunset, whereas during the day the fish resides closer to the bottom. The common tern does not show behaviour that indicates that it makes use of this mechanism. A 2x12 hours

observation of the birds in May and in August around De Kreupel shows that common tern does not show extra forage activities around sundown and sunset.
As a plunge-diver, common tern only utilises the top part of the water column, whereas the boat catches and cormorant uses the whole vertical column. When comparing the different birds and the boat catches in the same month the length the 0+ and 1+ smelt is shorter in the diet of the common tern than in the boat catches. This indicates that with increasing size, the 0+ and 1+ smelt swim lower in the water column, more out of reach for the common tern. The cormorant caught shorter smelt lengths, but is not dependable on smelt as common tern does.

Transparency levels in 2011 were slightly higher compared to 2010 (0.8m to max 0.7m in July). In 2011 values were high in Lake IJsselmeer in May (1-2m) and in June (0.9-1.8m). The transparency needed for cormorants to successfully hunt is in between 40-100 cm. This is probably less for a plunge-diving bird as the common tern. The high values in May and June could therefore have influenced the attainability of smelt in Lake IJsselmeer and made the terns to forage on Lake Markermeer.

Ruffe is able to predate on smelt eggs. An analysis of ruffe stomachs caught in presumed smelt spawning areas in Lake IJsselmeer and Lake Markermeer predates mostly on zoobenthos like Chironomidae and Gammaridae. Egg-like shapes were found in the stomachs, but analysis did not reveal if these were smelt eggs. However, it is believed that smelt egg predation is minimal, as spawning of smelt was only observed in Lake Markermeer. No large numbers of egg-like shapes were found in the stomach content of ruffe caught at that location.



(P. van de Ven, Lake IJsselmeer, 09-05-2011)

Contents

1. Introduction

The Lake IJsselmeer area is the largest lake complex in the Netherlands. It consists of Lake IJsselmeer, Lake Markermeer and Randmeren. The lakes have an important value for various species of birds and serve as breeding, wintering, moulting or as resting area during migration. At least 800.000 birds use the area. Based on these numbers all lakes in the Lake IJsselmeer area are wetlands of international significance (Ramsar-convention) and are subject to the Natura2000 law enforcement (European Bird and Habitat Directive, Noordhuis *et al.,* 2010).

In the 1990's various changes affected the number of piscivorous birds negatively. These negative developments have been linked to the decline in smelt stock (*Osmerus eperlanus)* and changes in transparency. As some of these bird species are subject to the Natura2000, the project ANT (Autonome Neergaande Trends) was initiated. ANT aims for "clear management advices for resilient and sustainable ecosystems with optimal possibilities for the target species" in 2013 (Noordhuis *et al.,* 2010). The following information is taken from Noordhuis *et al.* (2010) unless otherwise stated.

1.1 Trends in bird numbers

Since the end of the 1980s bird numbers changed in Lake IJsselmeer and Lake Markermeer. The number of herbivorous birds increased when submerged pants began to grow, benthivorous bird numbers decreased with a decrease of zebra mussel (*Dreissena polymorpha*) density, especially in Lake Markermeer. However, many of the benthivorous birds relocated to the Randmeren, where densities of mussels had increased. The piscivorous birds suffered the most. The number of piscivorous birds decreased over the years. A possible cause is the reduction of smelt stock, one of the most important prey species for birds during the eighties and nineties (Figure 1, see section 2.2). Focus in this study is on three species: the common tern (*Sterna hirundo*), the black tern (*Chlidonias niger*) and the cormorant (*Phalacrocorax carbo*). The first and the latter are breeding in the Lake IJsselmeer area, while the black tern visits the area in August and September during the migration to the south. The common tern and black tern hunt for food by plunge-diving in the water. As the bird does not dive into the water, only fish close to the surface are accessible. The cormorant dives in the water to hunt for fish and is able to catch fish in the whole water column with water transparency levels between 40-100 cm (van Rijn & van Eerden 2002).

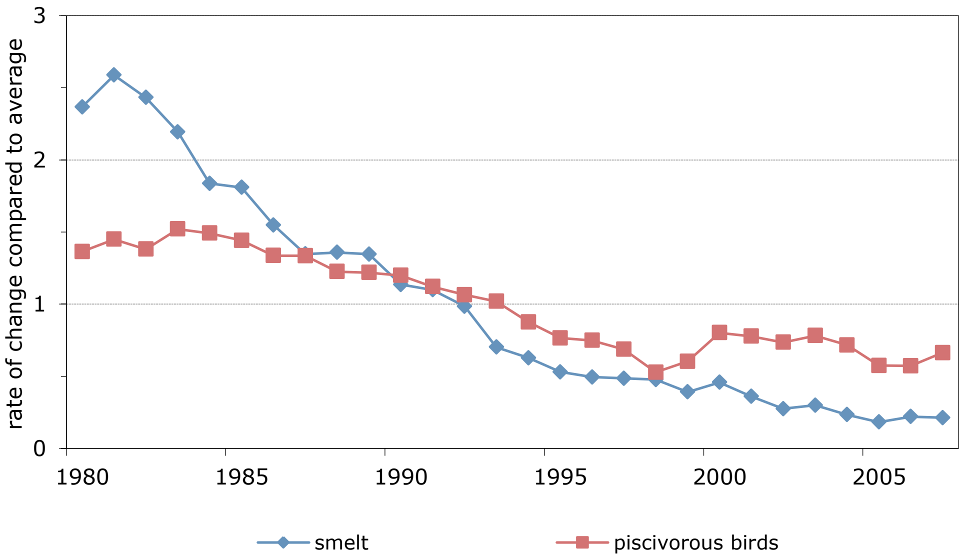


Figure 1.Indexed change of the biomass of smelt and the number of piscivorous birds (great crested grebe, common merganser, smew, black tern and little gull). The lines display the average smelt biomass per year and the average number of piscivorous birds per season (average of the seasonal averages of July to June of the next year). Taken from: Noordhuis et al., 2010

1.1.1 Common tern

The common tern (*Sterna hirundo*) was until 1989 a rare species in the Lake IJsselmeer area, as suitable breeding habitat was scarce. This changed when various nature development projects were carried out creating new breeding area. Large population growth occurred in 2003/2004, with the realisation of nature island De Kreupel. The population increased to around 5000 breeding pair in 2009 (Figure 2). This makes the colony of common tern on De Kreupel the largest in West Europe and forming a quarter of the Dutch population.

The last few years breeding success of common tern on De Kreupel was too poor to sustain a healthy population (Table 1, van den Winden *et al*., 2009). Even if the numbers in Lake IJsselmeer are still twice as high as the conservation objective, the breeding success is one of the most important factors to achieve this target and keep the population healthy. Furthermore, together with the poor breeding success on the other large colony on Griend (Waddenzee) the national objective in Natura2000 of 20.000 breeding pairs is in danger (Natura2000 doelendocument LNV, 2006). The poor breeding success on De Kreupel was probably due to the absence of sufficient 1+ smelt (smelt of one year old) (van den Winden *et al*., 2009). These fishes are needed for the growth of common tern chicks. As a plunge-diving bird, the common tern can only catch fish close to the surface. The bird flies back and forth to deliver fish to the young. When only delivering 0+ fish (young-of-the-year), the frequency would be too high (20-40 fish) to fulfil the energy demand of the chicks (van den Winden *et al*., 2009).

Table 1. Breeding success of common tern on De Kreupel (Bureau Waardenburg Sternwerkgroep, 2011)

Year	Qualitative breeding success
2007	Average
2008	Good
2009	Poor
2010	Poor
2011	Poor

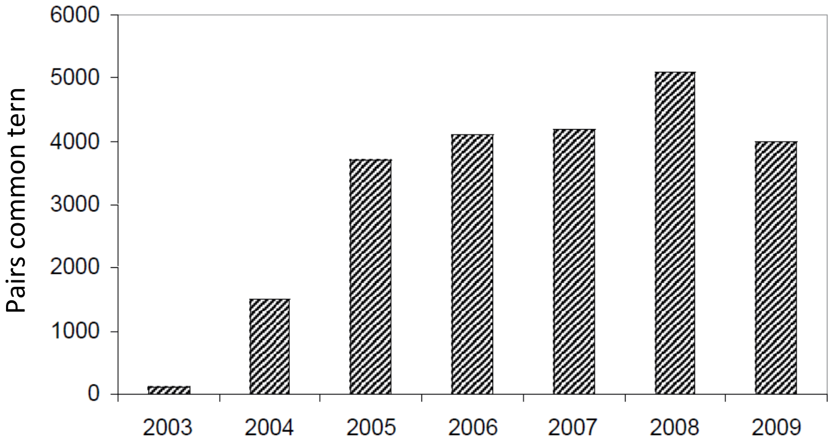


Figure 2. Number of common tern breeding pairs on De Kreupel since the year of construction. Taken from: van den Winden et al., 2009

1.1.2 Black tern

After the breeding season the black tern (*Chlidonias niger*) migrates from their breeding areas in East Europe and Siberia to the overwintering areas near the coast of West-Africa. During this migration the birds reside in the Lake IJsselmeer area (especially Lake IJsselmeer) primarily for moulting. 10% of the international population is found here in the months August and September.

Over the years, numbers of resting black terns started to fall (Figure 3). This was noticed in both methods in which the black terns were counted: aerial surveys and counts of individuals on the sleeping places. This corresponds with the decreasing numbers of moulting great crested grebe (*Podiceps cristatus*) (Figure 3). Noordhuis *et al.* (2010) suggests that there is a common cause, like for example a combination in the decline of the amount of smelt and changing transparency levels.

Since the realisation of De Kreupel, black tern (*Chlidonias niger*) began using the island massively as a rest area (berth), thereby making De Kreupel one of the largest resting areas for the black tern in Western Europe. But only in 2006 numbers in Lake IJsselmeer reached values close to those recorded before 1995 (Figure 3).

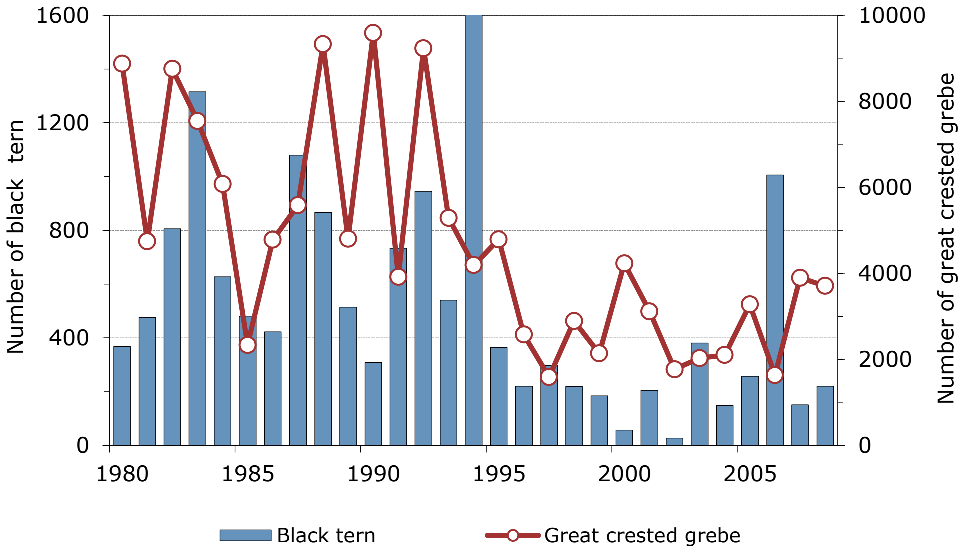


Figure 3. Comparison of developments in the number of black terns (Chlidonias niger) (season average of the total Lake IJsselmeer area) with the number of Great crested grebes in Lake IJsselmeer during the moult (Aug-Sept). Taken from: Noordhuis et al., 2010

1.1.3 Cormorant

While other piscivorous birds showed a decline in Lake IJsselmeer, the cormorant (*Phalacrocorax carbo*) population increased from the nineties onwards. Since the protection of the bird in 1965 the population in the Lake IJsselmeer area had grown, until in 1994 the numbers of breeding pairs in the two main colonies of Oostvaardersplassen and Lepelaarplassen suddenly dropped. After that many of the remaining pairs moved from these Lake Markermeer colonies to a location on the west coast of Lake IJsselmeer and the newly built island of De Kreupel in the centre of this lake, explaining the local increase. Also, the diet of the cormorant is different from other fish eating birds. Instead of smelt, ruffe (*Gymnocephalus cernua*) forms a large part of the food for the cormorant, and this fish species had increased quite a bit in Lake IJsselmeer.
As an opportunist, the cormorant quickly adapted to changes in the system. When around 1970 the transparency in the lakes decreased, the cormorants started to hunt for fish socially in groups, instead of solitary. In this way the birds can successfully hunt for fish with intermediate transparency levels in between 40-100 cm (van Rijn & van Eerden 2002).

The colonization of the Lake IJsselmeer area started from Naardermeer, south of the Lake Markermeer. The following and crucial step was the colonization of the Oostvaardersplassen in 1978. From there on the area Lepelaarsplassen was colonized in 1985. The total population peaked in 1990 till 1993 with 15.000-16.000 breeding pairs. 1993 marked the end of these high numbers with a poor breeding success, caused by a low stock of perch and ruffe and a low transparency (20-

30 cm) in Lake Markermeer. From this time on the total population fluctuated between 10.000-12.000 breeding pairs. Furthermore a shift from Lake Markermeer to Lake IJsselmeer took place. Nowadays there are seven colonies in the Lake IJsselmeer area. Still the colonies are not stable, as is displayed by the setback in Oostvaardersplassen and poor breeding success in 2007 in colonies around the Lake IJsselmeer. Possible causes are the warm month of April, with algal blooms in May and the low recruitment of ruffe in the last two years. Also in 2011 the breeding success was poor in Lake IJsselmeer, while colonies located around Lake Markermeer had moderate breeding success. The birds foraged mainly on Lake Markermeer, while the best forage grounds are on Lake IJsselmeer (pers. comm. Van Rijn, 2011). An unknown factor is causing the Lake IJsselmeer to be barely utilized, making Lake Markermeer more suitable.

1.2 Trends in fish abundance

An important cause of the decline of piscivorous birds is the reduction of the total biomass of fish in Lake IJsselmeer and Lake Markermeer (Figure 4). Especially smelt (*Osmerus eperlanus*), a key species in the system declined to less than 20% in 2000 compared to the population in the 1980's (Figure 5). Smelt is favourable to birds as it is a small pelagic species with a relatively high amount of energy.

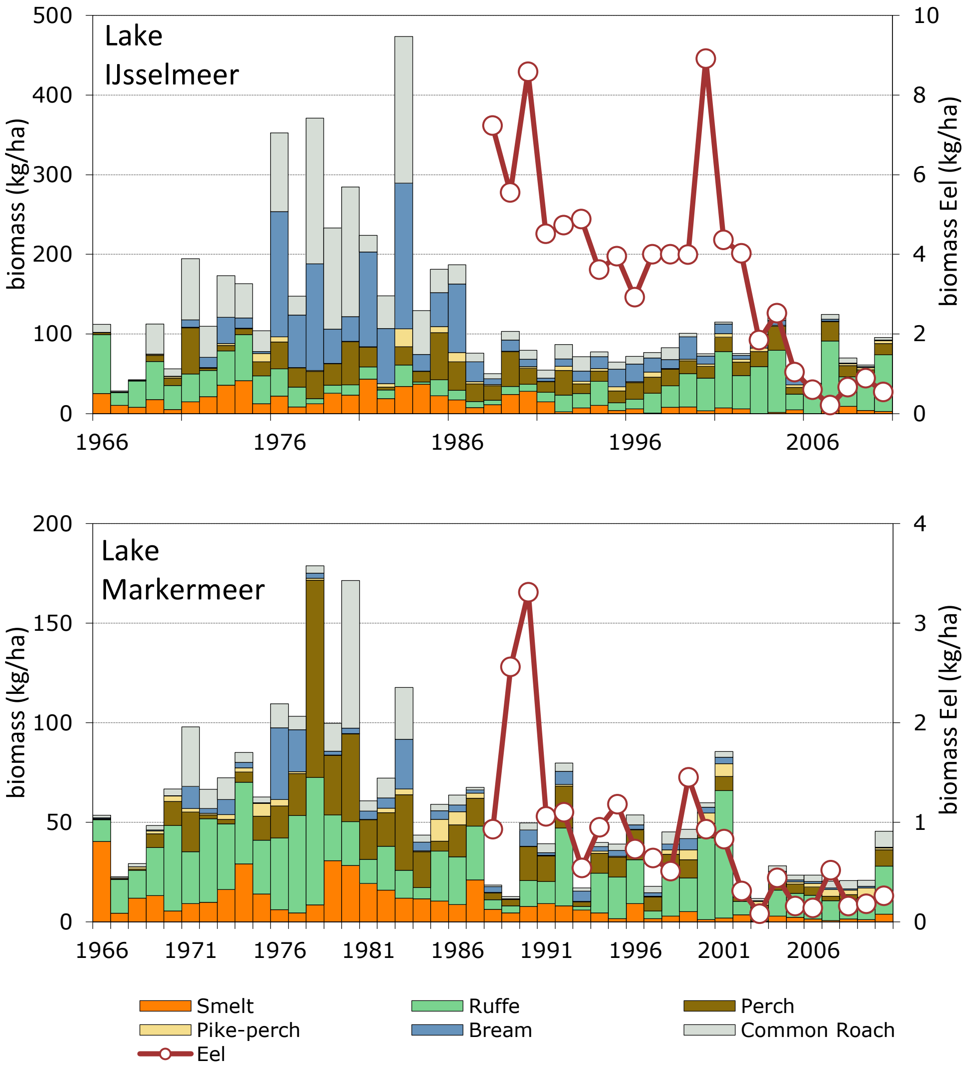


Figure 4. Development of fish stock in Lake IJsselmeer and Lake Markermeer based on sampling with the large cod end (Dutch: grote kuil) (bar chart, left axis) and for eel electrokor (line, right axis). The biomass of fish is a standardized index (kg caught per ha). Because of changes in catchability, some species could be over- of underrepresented. Taken from: Noordhuis et al., 2010

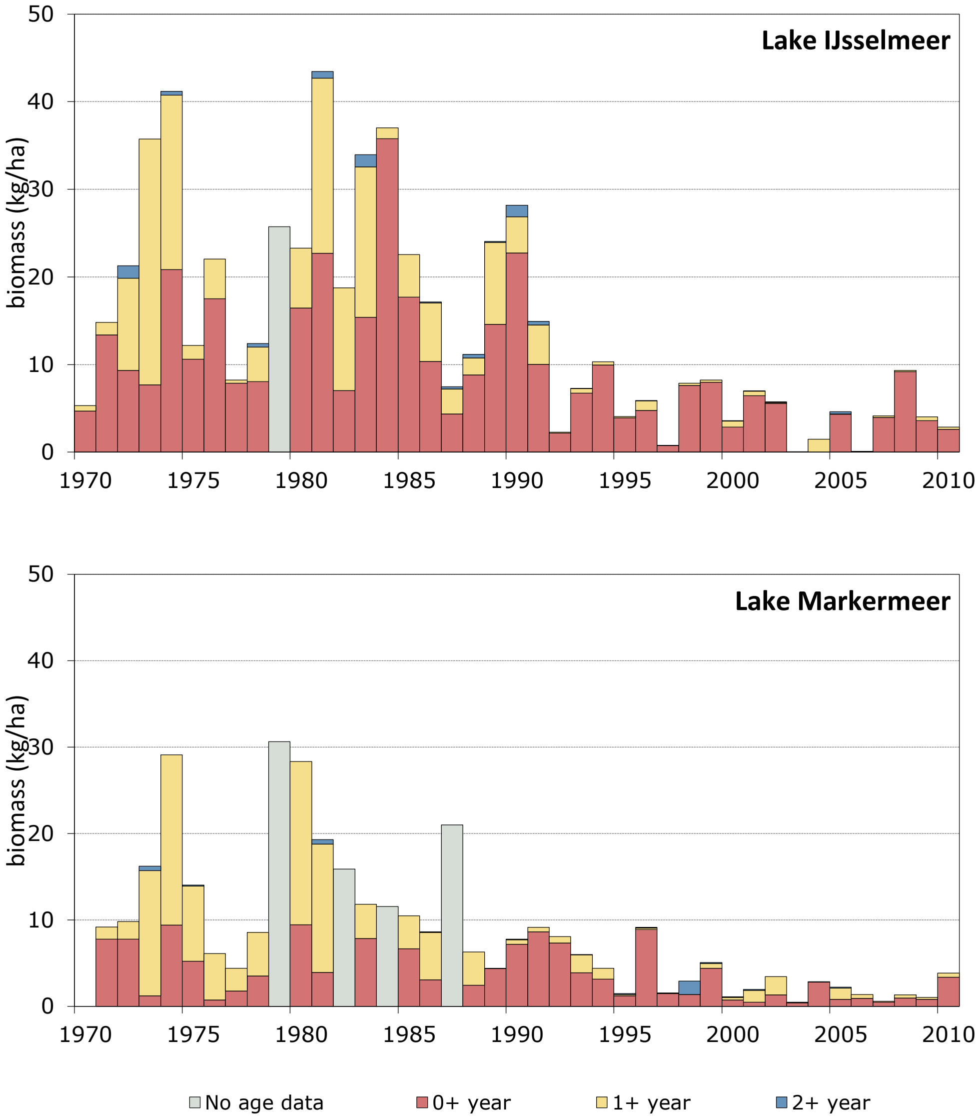


Figure 5. Developments in the smelt stock in the Lake IJsselmeer and Lake Markermeer based on the yearly fish stock samples with the large cod end (Dutch: grote kuil). Using the length distribution different age classes are distinguished. Taken from: Noordhuis et al., 2010

The possible factors that caused the decline (in availability) of smelt are the availability and quality of zooplankton (due to decrease in nutrients and/or mismatches between zooplankton and phytoplankton due to climate change), changes in transparency, making the fish harder to catch (light avoiding effect) and effects of warm summers (low oxygen-conditions because of algal blooms and high temperatures, more in section 2.3). The fisheries also influenced the fish stock in Lake IJsselmeer and Lake Markermeer. With the emerging fisheries on smelt in the eighties the proportion of 1+ smelt has gradually disappeared (Figure 5). Only ruffe (*Gymnocephalus Cernua*), a benthivorous fish species, increased in numbers. While it seems to be staple food for Cormorants, as a benthic species ruffe is hardly available to terns, which can only forage for fish in the top layer of the water column (plunge-diving). But as it is found increasingly in the diet of birds it now seems to become more an alternative out of necessity.

1.3 Possible causes of decreasing availability of smelt for piscivorous birds

As is described in the previous sections smelt is the most important species for fish eating birds. The decrease in smelt stock probably caused the bird numbers to decrease. Next to the fisheries, two other mechanisms could have caused the disappearance of smelt. These are 1) the change in phosphorous and nitrogen, leading to less food for the smelt and 2) Climate change, leading to mismatches in food availability.

The decline of phosphorous and nitrogen loads were results of various laws and regulations implemented in the Netherlands from 1970 onwards. However, as the quality of the water is largely dependent on the German river water, Germany had a large share in improvement of the water quality by improving waste water treatment from 1976 onwards. Loads of phosphorous and nitrogen decreased (Figure 6). The amount of suspended solids lowered and oxygen levels increased. Phytoplankton growth became nutrient-limited and chlorophyll concentrations dropped. Together with the improving water quality and the change in fish stock, transparency levels also improved in

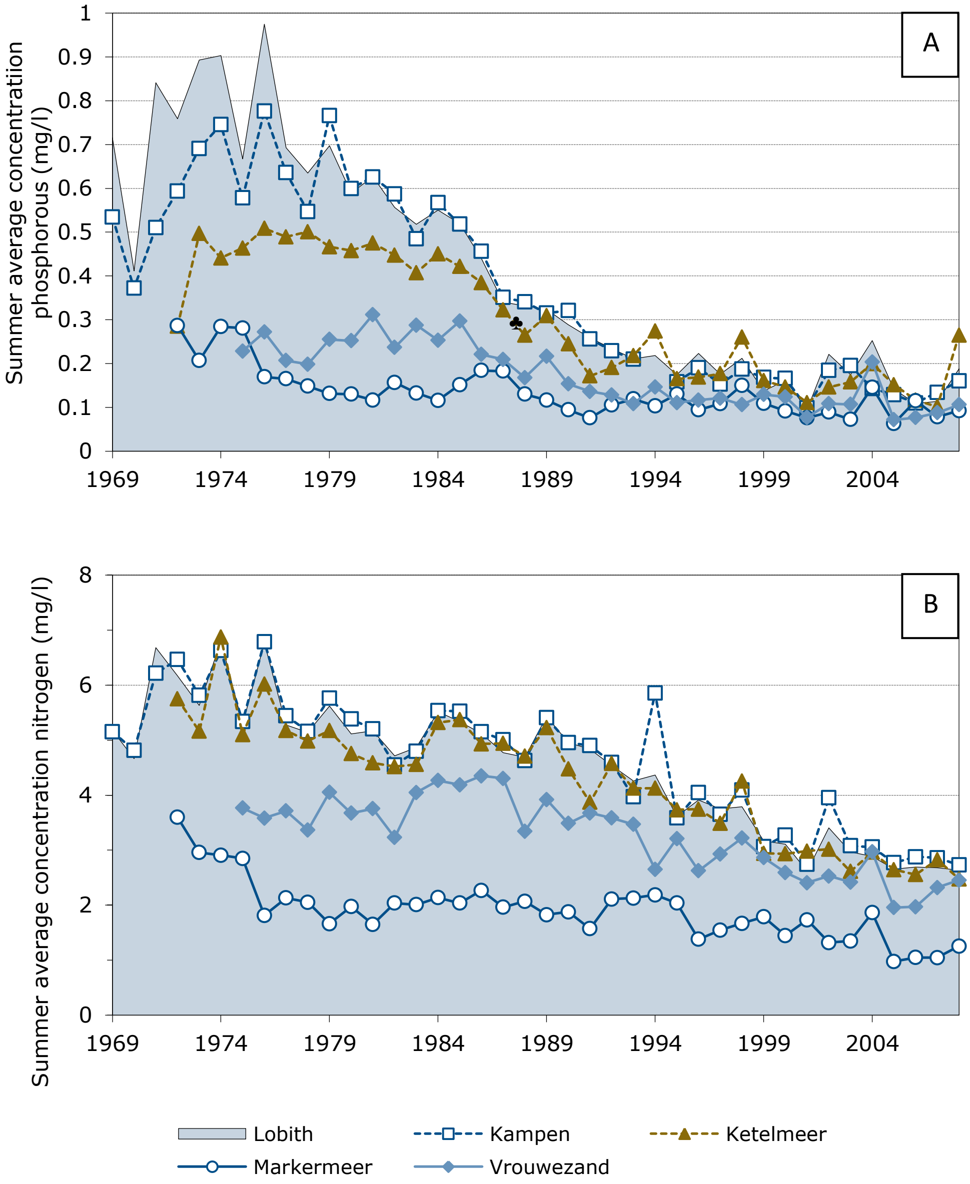


Figure 6. Comparison of the summer averages of total phosphorous (a) and total nitrogen (b) in the Lake IJsselmeer area, compared to the development in the Rhine by Lobith (grey area) and the IJssel by Kampen. Taken from: Noordhuis et al., 2010

more recent years (Noordhuis *et al.,* 2010). As smelt prefers turbid waters, the clearer water caused the fish to swim in deeper parts or closer to the bottom of the lake. As deeper parts are scarce in Lake IJsselmeer and Lake Markermeer, this could influence the behaviour and survival of smelt (Noordhuis *et al.,* 2010). Also, as smelt swims lower in the water column, attainability for plunge-diving birds decreases more.

The other mechanism causing a decrease in the smelt population is the climate change. There is little known about the effects of climate change in the Lake IJsselmeer area. The preliminary and brief results suggest a mismatch in food availability for smelt with the hatching of the smelt eggs. Smelt spawns at water temperatures around 6 °C. Spawning occurs at this temperature to coincide the hatching of larvae with the peak of zooplankton at 10-12 °C (the clear water phase). However, as the years are getting warmer, a change is visible in the date the smelt starts spawning. Since 1988 spawning occurred on average 20 days earlier (Figure 7). This change is not visible in the peak of zooplankton and a mismatch may occur, as zooplankton is thought to respond more to changes in day length than in temperature. Also, a change in species composition of phytoplankton may have resulted in poor food quality. This leads to lower food availability for the growing smelt, affecting population growth. This eventually translates in a smaller population smelt later in the season and a lower availability for the piscivorous birds (Noordhuis *et al.,* 2010).

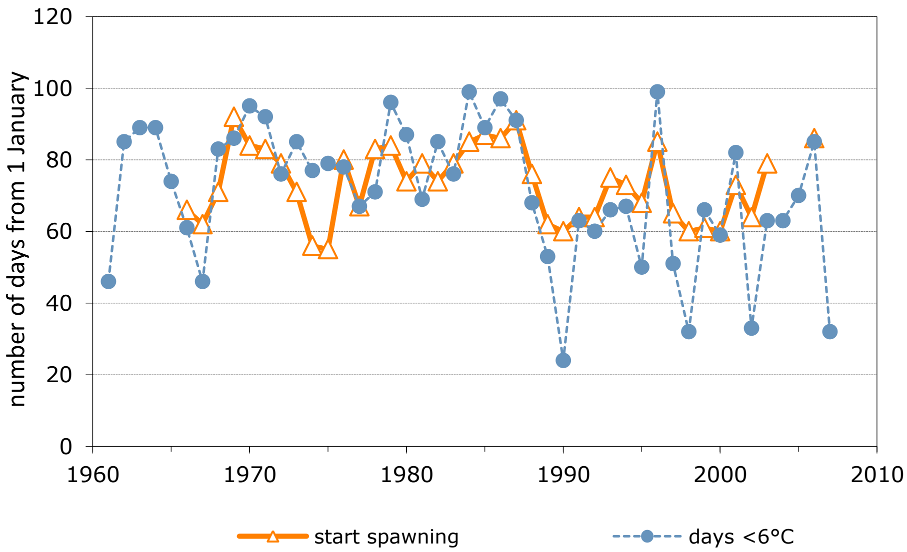


Figure 7. Development of the number of days in spring from 1 January with a calculated daily mean water temperature less than 6 °C, and the median spawn date of smelt in Lake IJsselmeer. Taken from: Noordhuis et al., 2010

The availability of smelt for the common tern is thought to be influenced by three aspects:

1. If smelt is available in Lake Markermeer and Lake IJsselmeer in numbers large enough to act as food source during the tern season;
2. If smelt is attainable for the common tern. Especially the 1+ smelt seems to be important during the fledgling stage (van den Winden *et al*., 2009). The attainability is largely dependent on the vertical distribution pattern of the fish. Water transparency plays a large role in this pattern. If the water is too turbid, the bird is not able to see the fish anymore. With too clear waters, smelt swims deeper into the water column, becoming unreachable for the plunge-diving tern. Mous *et al.* (2004) shows that a higher water transparency increased the depth where the 0+ smelt was concentrated during daytime. During night-time, smelt is more dispersed over the water column. During dusk, fish dispersed 1 hour before sundown and 45 minutes after sunset. This was also observed by Piersma *et al.* (1988). During these periods of sunset and sunrise smelt should become more attainable for plunge-diving birds to catch fish. Plunge-diving birds could react to this to go hunting around these times. Another method is to compare the differences in diet of

pelagic (terns) and dive hunting (cormorants) birds. During various field visits in 2007-2011 pellets of common tern and cormorant are collected and examined. With this information the attainability of birds in relation to the vertical distribution pattern of fish is studied;
3. A not bird-fish related aspect is the predation of smelt eggs by ruffe (*Gymnocephalus cernua*). While other fish species declined, this benthic fish species was the only one increasing in numbers (Noordhuis *et al.,* 2010). Literature states that ruffe is able to predate on eggs (Ogle, 1998). If this is true for Lake IJsselmeer and Lake Markermeer, as is hypothesized in de Graaf & Keller (2010), then this could influence the smelt stock and availability for birds. Based on these aspects the following main and sub questions are addressed in this report:

What is the relation of the common tern with smelt abundance and transparency levels in the Lake IJsselmeer area?

1. How much of the smelt available in Lake IJsselmeer and Lake Markermeer is attainable for the common tern?
2. What effect has the underwater climate on the attainability of smelt for the common tern?
3. What is the amount of 1+ smelt in the diet of the common tern?
4. How does the predation of ruffe on smelt eggs have effects on smelt stock later in the season?

2. Methods

The procedures to study the questions in the introduction are described in this chapter. The attainability of smelt for common tern is depending on the availability of the fish in the lakes. Only data from 2010 and 2011 are compared to each other. The attainability of fish for common tern is further determined by the underwater climate. Differences between common tern and cormorant give additional insight in the attainability and the placement of fish in the water column. Smelt egg predation by ruffe is examined by inspecting stomachs of ruffe caught during the spawning period of smelt.

2.1 Availability of fish

For the availability of fish in the common tern season data from the ANT cluster small fish (Imares) was used. Each month a boat sets sail in the Lake IJsselmeer and Lake Markermeer to haul in fish and measures transparency with a Secchi disk (section 3.3.3, Figure 8). The length of the net used was 4m; the opening was 1,5meters high and 3 meters wide. The mesh size was 5 mm from knob to knob. The boat hauled with a speed of 2.2 knots. Fish were identified and measured (in millimetres) in the field. Weight was later calculated with the formulas used in annex 1 (see paragraph 2.2). With large hauls, mostly consisting out of smelt, all other individual fish were taken out and a subsample of smelt was taken. The amount of hauls varied with each month. This is seen in Table 2. For this study it is assumed that fish in Lake IJsselmeer and Lake Markermeer are homogenously distributed.

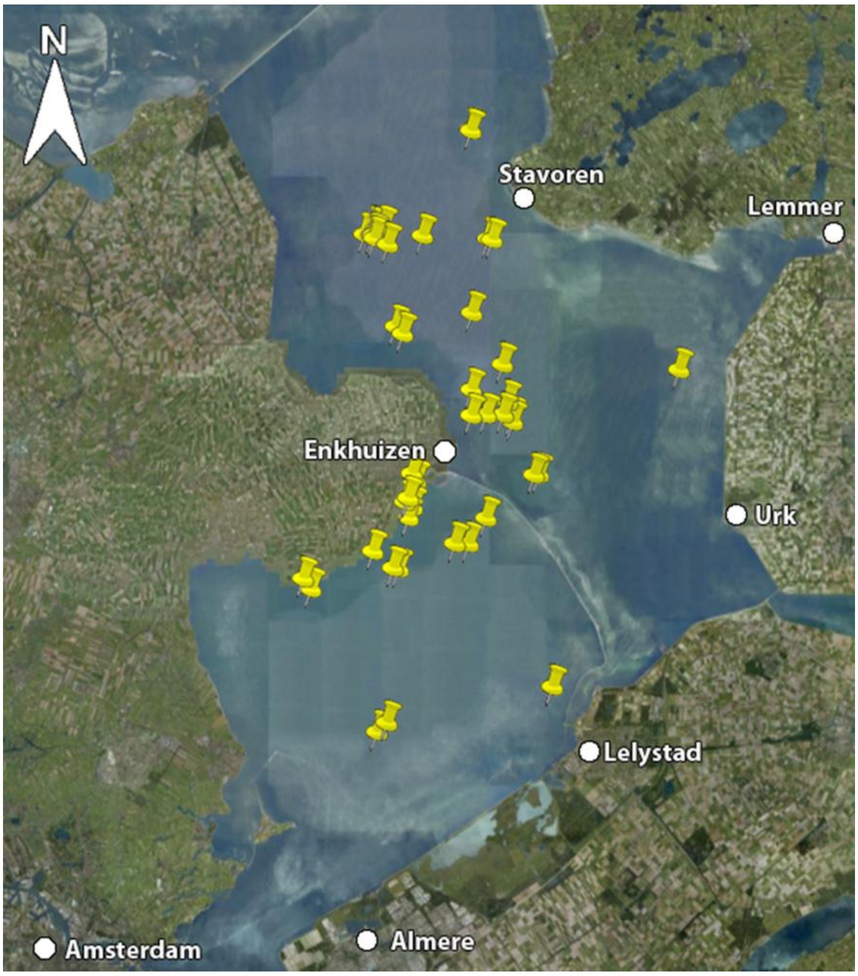


Figure 8. Boat hauls in Lake IJsselmeer and Lake Markermeer in 2010 and 2011 in the months 5-9 (GoogleMaps, 2011)

In august 2011 a fisherman from Lake IJsselmeer and a fisherman from Lake Markermeer helped collecting smelt for this research. The smelt were caught in Lake IJsselmeer in Vaarwater. On Lake Markermeer the fisherman hauled for smelt three kilometres outside the town of Volendam. The depth was around two meters. Smelt was barely caught and the water was extremely clear (“tap water”, no Secchi depth available). The smelt was measured and weighed in the lab to determine the length-weight relation (see paragraph 2.5 and 3.6)

*Table 2. Amount of monthly boat hauls carried out in the common tern season of 2010 and 2011 per month. *: exact day not known*

	Lake IJsselmeer		Lake Markermeer	
Year	**Date**	**Amount of hauls**	**Date**	**Amount of hauls**
2010	12-05	2	12-05	1
	14-06	1	08-06	1
	06-07	2	06-07	3
	18-08	2	18-08	1
	*-09	3	*-09	1
2011	19-05	4	19-05	2
	14-06	11	15-06	8
	11-07	2	11-07	1

2.2 Diet of birds

During various field visits in 2007-2011 pellets of common terns were collected and examined. Also pellets of cormorants were collected and examined (Table 3). These pellets give insight in the diet of the birds and can be coupled to the fish stock in the lake. Furthermore the data of the diet is useful to study the differences between the common tern and the cormorant. As the study focuses on 2010 and 2011, only in July and September 2010 diet of the common tern and the cormorant could be compared.

Figure 9. Colonies of common tern (green) and cormorant (blue) in the Lake IJsselmeer area (GoogleMaps, 2011)

Common terns and cormorants produce a pellet every day to get rid of indigestible fish remains. These pellets are useful for determining the daily food intake. This kind of information obtained from the cormorant was used to show long term changes in the water system. Pellets of common tern were mostly sampled at De Kreupel, where 95% of all common terns in the area reside, and one time at Hoeckelingsdam, north of Amsterdam. During all this visits, only intact and complete pellets were collected. Pellets of cormorant were collected at the various colonies (Figure 9 and
Table 3). For cormorants this was easy as the fish remains were embedded in mucus, acting as a film. Common tern pellets are drier and more prone to dispersion, so extra care was taken that the whole pellet was collected. Young cormorants and young common terns do not produce pellets, so only the diet of the adult bird is obtained (van Rijn & van Eerden, 2002 & pers. comm. van Rijn, 2011). Pellets were collected in plastic bags and stored in a freezer the same or the day after collection. All collected pellets were examined.

Table 3. Number of pellets collected and examined in the lab for common tern and cormorant

Common Tern				**Cormorant**			
Date	**Location**	**# pellets**	**# preys**	**Date**	**Location**	**# pellets**	**# preys**
07/07/2010	De Kreupel	29	191	28/05/2010	Oostvaardersplassen	6	343
20/08/2010	De Kreupel	98	693	10/06/2010	Enkhuizen De Ven	31	1366
24/09/2010	De Kreupel	53	356	14/06/2010	Oostvaardersplassen	15	721
				18/06/2010	Naardermeer	28	620
2010	**Total**	**180**	**1240**	19/06/2010	Lepelaarsplassen	27	1037
				07/07/2010	De Kreupel	38	1424
05/07/2011	De Kreupel	35	112	24/09/2010	De Kreupel	35	1732
07/07/2011	Hoecke-lingsdam	51	269	**2010**	**Total**	**180**	**7243**
14/08/2011	De Kreupel	10	51	10/05/2011	Onderdijk/Vooroever	16	514
				23/05/2011	Oostvaardersplassen	5	173
2011	**Total**	**96**	**432**	26/05/2011	Enkhuizen De Ven	24	787
				01/06/2011	Oostvaardersplassen	21	822
2010-2011	**Total**	**276**	**1672**	**2011**	**Total**	**66**	**2296**

During the analysis of the pellets all recognizable and usable fish remains were taken out of the pellet and determined under a binocular. Most common were the ear stones of the fish, called otholiths, which are different for each species of fish. For carp-like fish (cyprinids), otholiths are similar to each other and therefore chewing pads (piece of the cartilage from the top of the mouth cavity) and pharyngeal teeth (set of two bony parts of gill-apparatus adapted for chewing against each other and the chewing pad) were used for species identification. When only otholiths of carp-like fish were found, the species was written down as *cyprinid spec*. Other identifiable fish remains (jaws, parts of the operculum, shoulder-bones and scales) were used if no otholiths, chewing pads or pharyngeal teeth were found or if these other fish remains clearly belonged to another fish species. Next to fish other prey was also found in the pellets, like seeds and insects. These are not used in this study.

All otholiths were measured on the long side with the internal ruler of the binocular in millimetres. When large amounts of otholiths of a certain species were found in a (cormorant) pellet, only a subsample (minimum 20 pair) was measured. The remaining otholiths were counted, divided by 2 and the average length of the measured otholiths was assigned to them. Chewing pads were also measured on the long side; the pharyngeal teeth were measured on the shortest side of the maximum number of left or right occurring teeth. When measuring chewing pads and teeth of the same fish, preference goes to the chewing pads. These remains were more accurate in approximating the actual length and weight of the fish. Pharyngeal teeth were, most of the time, damaged when they were taken out of a pellet. When only otholiths were found, lengths were estimated based on known fish lengths by chewing pads or teeth with the corresponding otholiths. With the lengths of the otholiths, pharyngeal teeth, chewing pads and regression formulas the length of the fish could be reconstructed. With the fish length and other formulas the weight of the fish was calculated. The used formulas are presented in annex 1.
For some fish the regression formulas for measuring length and weight based on otholiths is not known. As these fish were hardly caught, effect would be barely noticeable. But to have the full picture, for these fish the following rules are applied (pers. comm. van Rijn, 2011):

- The formulas of the perch is used for ninespine stickleback (*Pungitius pungitius*) and three-spined stickleback (*Gasterosteus aculeatus*);

- The formulas of roach is used For Ide (*Leuciscus idus*) and Rudd (*Scardinius erythropthalmus*) for otholiths of *Cyprinid spec*. it is assumed that the individuals were small fish in the range of 1-10 cm. Based on this a linear line is plotted with: Fish Length (mm): (100* otolith length)-40. For weight the formula of roach is used;
- For freshwater bullrout (*Cottus perifretum*) a standardised weight of 3 gram is taken (Koffijberg & Platteeuw, 1997 in van Rijn & van Eerden, 2002)

The formulas presented in annex 1 were not applicable for fish which were identified from other fish remains. The length of those fish was measured by taking the average length of all the fish caught of the same species and the same date.

Smelt is further categorized into 0+ (young-of-the-year) and 1+ smelt, as this seems to be the most important fish in the diet of the common tern (Van der Winden *et al.,* 2009). For this classification the length-weight relation was plotted for each month per location per method (common tern, cormorant or boat haul). Between the 0+ and 1+ year class a distinguishable gap exists (example Figure 10). Graphs that do not show a gap were compared to graphs from the adjacent months and by creating histograms displaying the amount of smelt per cm, so that peaks of 0+ and 1+ smelt could be distinguished. The division of 0+ and 1+ smelt is in between the two peaks (Example Figure 25).

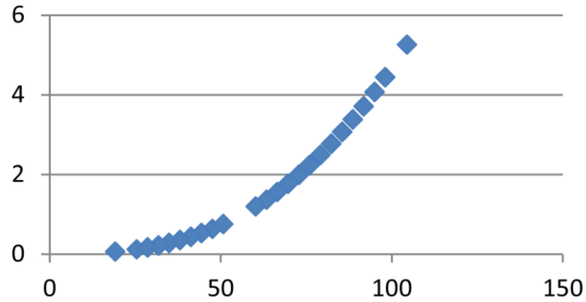


Figure 10. A length-weight graph of smelt from July 2011 with a clear gap (at 60mm) between the 0+ and 1+ year classes

Another method of examining the diet of birds is by taking pictures of passing birds with prey returning to their nest on De Kreupel. During three field visits (Enkhuizen de Ven, 30-05-2011; Hoeckelingsdam 05-07-2011 and De Kreupel 07-07-2011) pictures were taken by Stef van Rijn. When viewing the pictures on a computer, the fish can be determined (see Figure 11). Length of the fish is based on the standard length of the beak of the tern. This length is set at 3.6 cm (Cramp, 1985). Based the location where the photos were taken and the forage range of the common tern, the foraging area of the terns was calculated.


Figure 11. A common tern with a smelt in his beak (S. van Rijn, Enkhuizen de Ven, 30-06-2011)

With the diet of the common tern and cormorant insight can be obtained in the food consumption for both birds. Only diet of cormorant populations around Lake IJsselmeer were compared to the diet of the common tern population on De Kreupel. It is assumed that these cormorant colonies mainly forage on Lake IJsselmeer. On Lake Markermeer the birds can forage on smelt that differ in condition because of its own water quality and under water climate (more in paragraph 2.3.2).

2.3 Attainability

This study focuses on the attainability of fish as food for piscivorous birds. This is divided in two parts. First is the relation of position of fish in the vertical gradient, where the underwater climate has a large impact on the attainability of fish for birds. The transparency has an effect on the position of smelt in the water column and the catchability of the fish. If the water is too turbid

(Secchi depth <0.4 m for cormorants), birds cannot see the fish (van Rijn & van Eerden, 2002). If the water is too clear (Secchi depth > 1.0 m), fish swims closer to the bottom (Mous *et al*., 2004), becoming unreachable for the plunge-diving birds. Transparency data is collected by the ANT cluster fish (Imares, Marieke Keller) after the boat hauls using a standard 30 cm diameter Secchi disk. The disk was attached to a rope with 0.1 meter markings. Depth was noted down in decimetres.
Second is the relation of fish to the day-night rhythm. Previous measurements indicated that smelt distributes more evenly in the water column around sunset and sunrise and therefore swims closer to the surface (Piersma *et al*. 1988 & Mous *et al*., 2004). During these times smelt would become more easily available for the plunge-diving birds. This would be visible in an increased activity of the common tern during these times.

2.3.1 24-hour measurement

In May and in August 2011 daily patterns of activity of plankton, fish and birds were studied in the field by repeating sampling every one or two hours. In this report focus is on the birds. The first 24-hour measurement was set at the breeding start of the common tern, in the week of 9 May after arrival of the birds from the wintering areas. The second time was planned when the young were full grown and have left the nest and around the peak of migrating black tern (Table 4). The research was planned for 24 hours, divided over two days. The measurements started at around 14.00 till around midnight (approximately 12 hour measurement time). The next night the measurements were continued till the 24 hours were completed. For matter of convenience 24-hour measurement is maintained throughout the report.

Table 4. Dates of the vertical gradient experiment

#	Date	**Bird stage**
1	9 & 11 May	Breeding/courtship common tern
2	15 & 17 August	Peak black tern

Area selection
Originally, observations were planned to take place south of island De Kreupel in Lake IJsselmeer (Figure 12). However, because the preliminary results of May were poor, the decision was made to relocate to the north of De Kreupel, based on bird foraging movements and on information a fisherman had provided about the best smelt location.

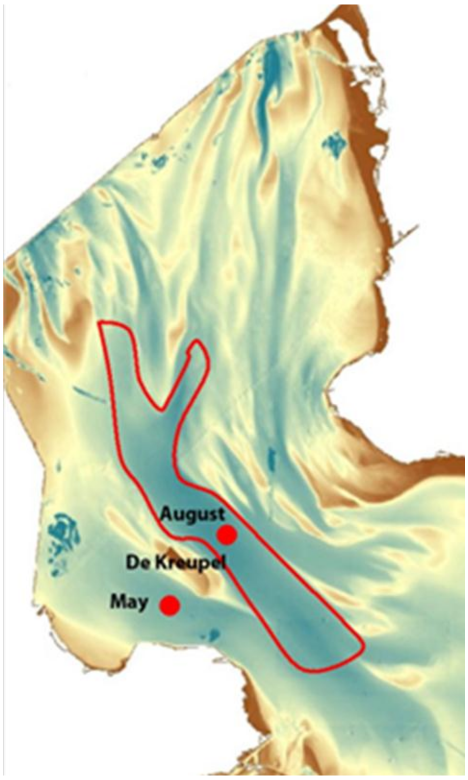


Figure 12. Best smelt area (information fishermen) and location for the 24h experiment measurement in May and August

Measurement interval
For the fish catches every two hours, and every hour near dusk and dawn hauls were performed. The same schedule was applied to the sampling of algae and zooplankton. Bird numbers were noted down every hour and every half hour around sunset and sunrise.

Fish
To examine the vertical gradient two nets placed vertically above each other were used. One net covered the first two meters of the water column and the second net covered the last two meters closest to the bottom. In this way the availability for plunge-diving and diving birds was measured and kept apart for as much as possible. One haul of the nets took at least 15 minutes and the boat sailed with a speed of 2.2 knots around the stationary boat(s) with a wide arc. The mouth of the net was 3 meters wide and 1.5 meters wide, mesh size was 5 mm (knot to knot) and the length of the

nets were around 4 meter. In addition hydro acoustic equipment was deployed to record the fish movements in the water. A tripod with a sensor was placed on the bottom of the lake. This sensor continually emitted a beam which was received by another sensor on board of a small boat. The sensor sent the data to a computer where it was recorded on a hard disk. This data is processed on a computer by the ANT cluster fish (Marieke Keller, Imares).

Water and zooplankton

Transparency was measured using a standard 30 cm diameter Secchi disk. The disk was attached to a rope with 0.1 m markings. It was lowered in the water, and the depth at which the disk was just visible was noted down in dm.

Water samples were collected at the surface and at 0.5, 1, 2, 3, 4 and 5 meters depth with a 5 l sampler. Samples were collected in triplo. Zooplankton was collected filling a small tube from the collected sample and the addition of fixate. The rest of the sample was led through a sieve, and the particles and algae that remained behind were collected and fixated. The samples are examined by the ANT cluster filterfeeders (Dirk Sarpe, NIOO).

Birds

In May, bird species, numbers, behaviour and zone where the birds resided at the moment were recorded on a map. The bird observer was Phillip van de Ven, watching with an 8x56 binocular on a moving boat. In August, the studied area was divided into sections with distinct borders (features in the landscape). In these sections species, numbers and behaviour were recorded. The bird observers were Ruurd Noordhuis (15-08) and Stef van Rijn (17-08) together with the Phillip van de Ven (15-08 and 17-08). Binoculars used were 10x42 and 8x56. Observations were made from a stationary boat. The maximum range in which birds could be counted and identified was set at 2.6 km, the distance of the measurement point in August to the farthest point of island De Kreupel. Large groups of foraging cormorants and accompanying terns were easily noticeable outside this range and estimations of bird numbers of these groups were written down apart on a map.

Differences between measurement moments

A difference between both 24-hour measurements was the amount of boats used for this experiment. In May only two boats were used, one stationary small boat for the hydro acoustic equipment, and one for catching fish, bird watching and collecting zooplankton and algae. In August three boats were used: one stationary small boat for the hydro acoustic equipment, one boat for the hauling of fish and one stationary boat for bird watching and collection of zooplankton and algae samples.

2.3.2 Comparison diet common tern and cormorant

In addition to the 24-hour measurement the vertical distribution of 0+ and 1+ smelt could be analysed by comparing the common tern with the cormorant. It was expected that the cormorant predated on a wider range of fish species and fish lengths compared to the common tern because of its larger size and opportunistic behaviour. The common tern would be restricted to the pelagic layer and small fish (<10 cm) only. However, as land-locked smelt scarcely reaches lengths longer as 10 cm (de Graaf & Keller, 2010), the largest part of the population should also available for common tern. No direct comparisons could be made in 2011. Only for the months July and September 2010 comparisons could be made, as in these months at the same day pellets of common tern and cormorant were collected at De Kreupel.

2.4 Predation of ruffe on smelt eggs

As is known from literature, ruffe (*Gymnocephalus Cernua*) tends to eat fish eggs. Ogle (1998) mentions several studies where eggs of smelt were eaten under lab conditions as well as in the field. However, in the same article indications were given that other studies showed egg predation by ruffe was low or non-existent. Ruffe numbers increased in Lake IJsselmeer in the nineties (Noordhuis *et al.*, 2010) and predation on smelt eggs in Lake IJsselmeer and Lake Markermeer could have increased also. If this predation is significant, it could influence the smelt stock (and the attainability for birds) later in the season.

Figure 13. The four sampling locations for predatory fish stomachs / spawning areas smelt (crosses) on 24 or 29 March (GoogleMaps, 2011)

Ruffe was sampled on presumed smelt spawning locations at the time smelt was spawning. Four locations were chosen, three in Lake IJsselmeer and one in Lake Markermeer (Figure 13). At each location 2 pair of fyke nets were placed in the water on 24 March and/or 29 March (Table 5). The nets were taken out of the water the next day. The caught fish was identified and ruffe was fixated in alcohol. The stomachs of big fish (larger than 10 cm) were taken out and conserved, while smaller fish were decapitated and a cut was made in the belly of the fish. This is to allow the fixate to conserve the intestines. Furthermore a small sample of smelt eggs deposited on the nets was fixed in alcohol to compare it with the egg-shapes found in the stomach content.
In the lab the stomachs were extracted from the fish, opened and the content was viewed with a binocular. Most of the contents, like zooplankton, were only determined to family-level; as more attention was spend in finding eggs. Unidentifiable contents were photographed and showed to experts.

Table 5 .Amount of ruffe examined per location and date

Location	**Date taken out**	**# ruffe caught**	**# ruffe examined**
Andijk	30/03/2011	36	20
Flevocentrale	25/03/2011	42	28
Houtribdijk	25/03/2011	15	15
Vrouwezand	25/03/2011	13	9
Vrouwezand	30/03/2011	31	31
Total		**137**	**103**

2.5 Real length-weight relation versus calculated length-weight relation of smelt

In August, a sample of smelt was caught in Lake IJsselmeer and lengths and weights were recorded. To calculate the weight of smelt based on the weight two formulas could be used. The formulas are:

1. Ln(Fish weight) = -10.903 + 2.702 * Ln(Fish length)
   (Platteeuw, 1988 in van Rijn & van Eerden, 2002)
2. Fish weight = 0,0042* Fish length (cm)^{3,2}
   (Fishbase, 2009 in van den Winden *et al.*, 2009)

The comparison between the real length-weight against the calculated length-weight is primarily used to compare which formula has the best fit against the actual length-weight relation. This is then used for the calculation of smelt in the diet of the common tern and the cormorant. Furthermore this comparison can be used to give an impression of the condition of an individual fish around 1988 and 2010.

2.6 Statistical procedures

The data obtained of the diet of the common tern, cormorant and data obtained of the boat catches were not normally distributed. This was tested using tests of normality (Shapiro-Wilk) with an α of 0.05. Only non-parametric test were applicable. The following data was tested in IBM SPSS Statistics 20© with the appropriate tests and an α of 0.05:

- Mann-Whitney U tests were used to test for differences in the length of 0+ and 1+ smelt in the similar months of 2010 and 2011
- a Kruskal-Wallis test was used for the comparison of the total fish weight of the pellet, the number of fish per pellet and the weight of the individual fish consumed by the common tern in each month
- The comparison of the proportion of 0+ and 1+ smelt in the diet of the common tern was tested with a Kruskal-Wallis test for 2010 and 2011. A Mann-Whitney U test was used to test for differences between the months
- The lengths of 0+ and 1+ smelt caught by common tern in similar months in 2010 and 2011 were compared by testing with a Mann-Whitney U test
- Differences in lengths of 0+ and 1+ smelt found in the same month in the diet of the common tern and cormorant and found in the boat catches were tested with a Mann-Whitney U test

3. Results and discussion

3.1 Availability of fish

In the common tern seasons of 2010 and 2011 smelt was the most caught fish and probably still the most abundant food for fish eating birds in both lakes. The data displays large variation for both Lake IJsselmeer and Lake Markermeer. Lake IJsselmeer contained in 2010 more smelt compared to 2011 and in 2011 smelt was more abundant in Lake Markermeer than in Lake IJsselmeer (Figure 14).

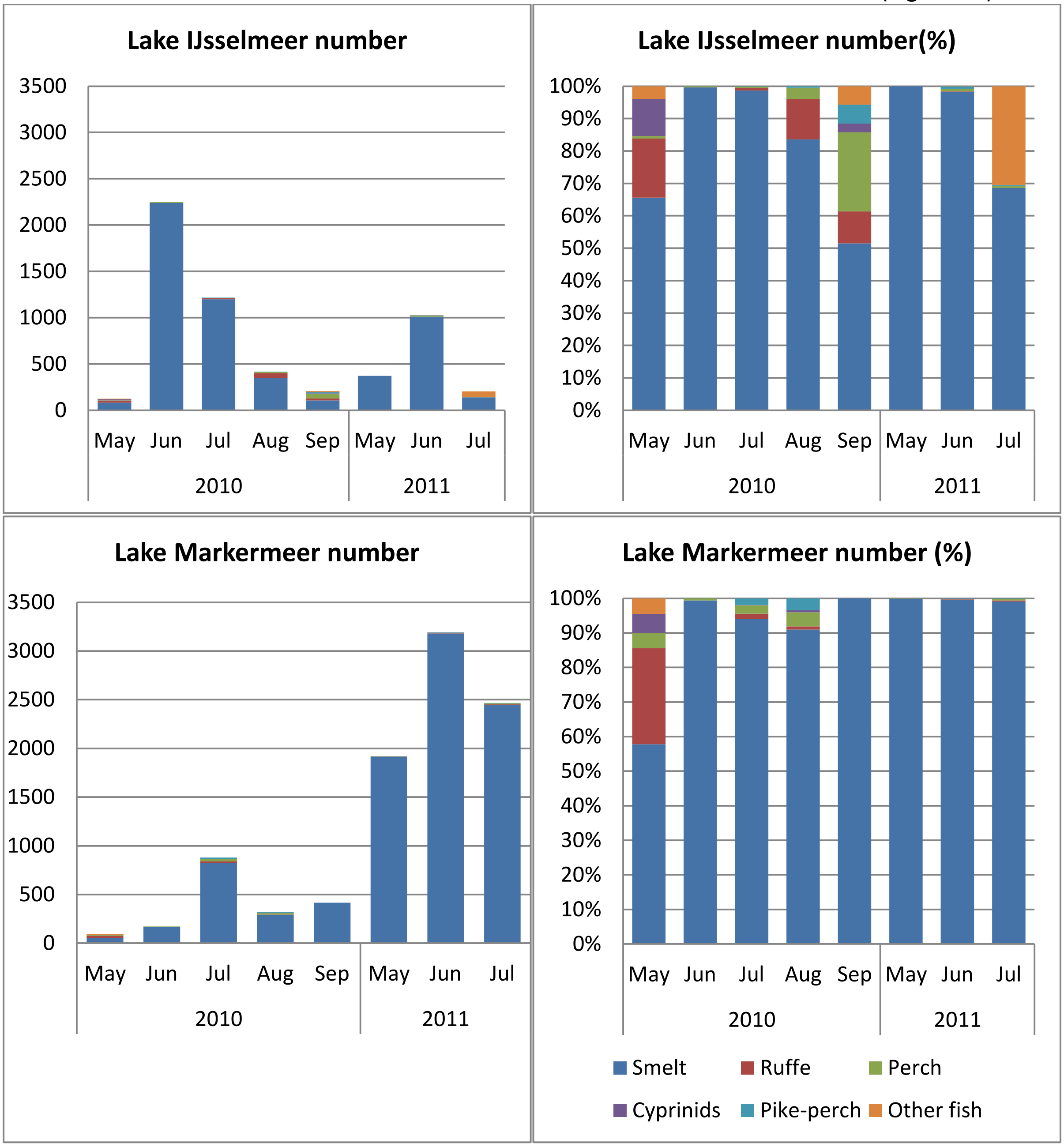


Figure 14. Left side: Numbers of fishes caught divided by the amount of hauls in Lake IJsselmeer and Lake Markermeer, based on numbers, Right side: idem relative (%)

In 2010 influx of 0+ smelt in Lake IJsselmeer was in June whereas in 2011 this occurred earlier, but in lower total numbers. Influx of 0+ smelt occurred in Lake Markermeer in 2010 one month later and in lower numbers. However, in 2011 Lake Markermeer had an early influx with a higher influx of 0+ smelt in comparison to 2010 and Lake IJsselmeer (Figure 15). Conditions for spawning (e.g. water temperature of 6 °C) were probably satisfied earlier. This seems consistent with the fact that the months of January and February were 3.5 °C warmer on average in 2011 compared to 2010 (Noordhuis *et* al., 2011; KNMI, 2012; pers. comm. Noordhuis, 2012).
1+ smelt was barely caught. This could be due to the species- and size-dependent swimming speed. As is explained in van Rijn & van Eerden (2002), fish were not caught when they swim faster than the speed by which the nets are hauled with the boat. Furthermore, when transparency levels are high, fish could see the net and evade it. Swimming speed is also affected by temperature. It seems likely that 1+ smelt has a higher rate of escape than the 0+ smelt, because of the size dependent swimming speed. Also, as a short living species, a part of the smelt dies after spawning, making availability decline (de Graaf & Keller, 2010; van Eerden & bij de Vaate, 1984). This means that after spawning the stock of smelt is low, until the new of the year are large enough to be caught by the birds.

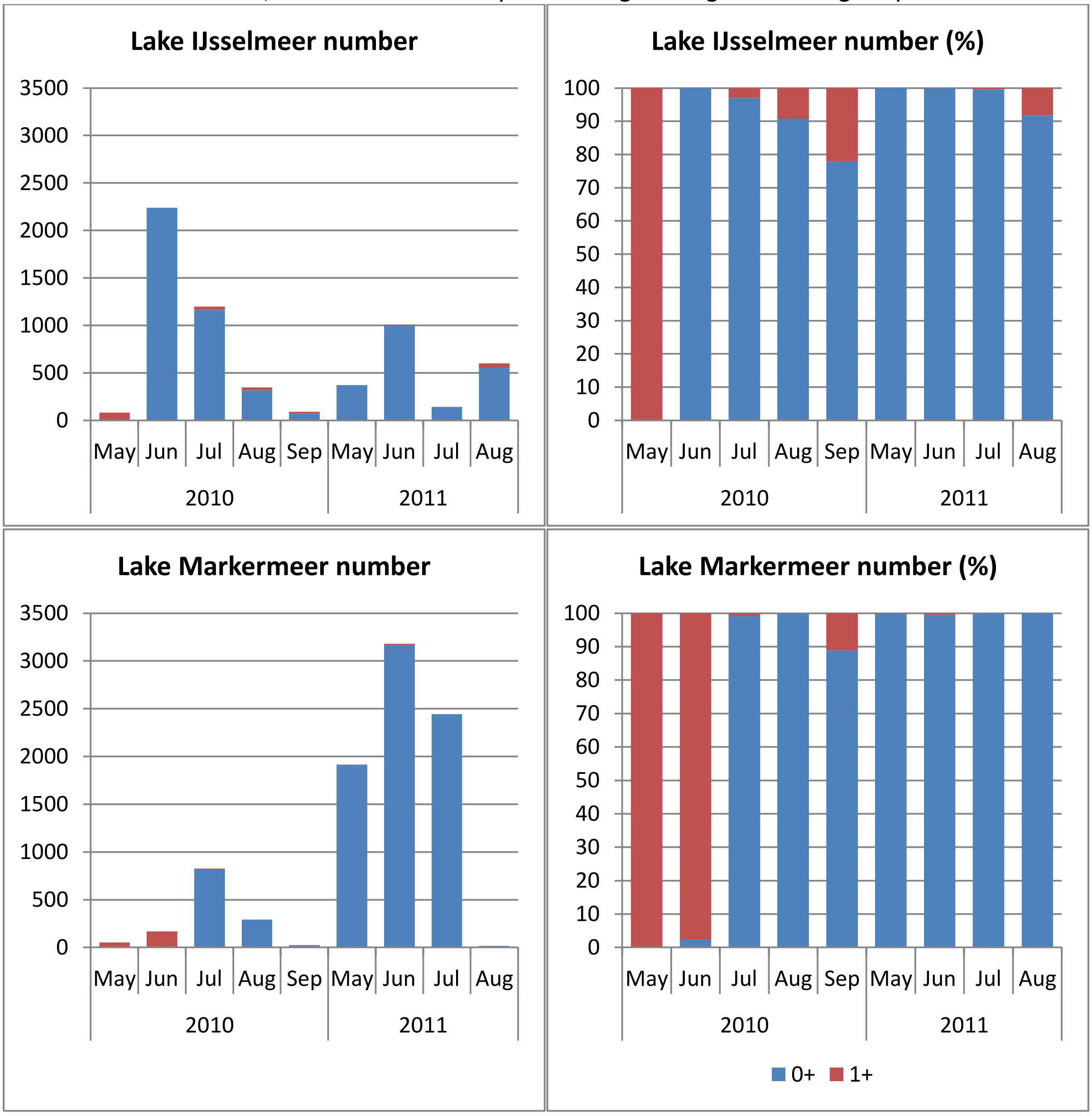


Figure 15. Left side: Numbers of 0+ and 1+ smelt caught divided by the amount of hauls in Lake IJsselmeer and Lake Markermeer for 2010 and 2011, based on numbers, Right side: idem relative (%). Smelt in August 2011 in Lake IJsselmeer and Lake Markermeer is caught by fisherman

Smelt of 0+ and 1+ age classes were longer in all months in 2011 compared to 2010 for both Lake IJsselmeer and Lake Markermeer (Mann-Whitney U test, $p<0.05$ for all cases, Figure 16, Annex 2). Comparing growth rates (cm/month), 0+ smelt in Lake IJsselmeer of both years shows the same pattern with 1 cm growth per month. The same is true for 0+ smelt in Lake Markermeer in 2010 and 2011.
As smelt was larger in Lake IJsselmeer than in Lake Markermeer in 2011, it should be more favourable for the common tern. However, observations in Enkhuizen de Ven at the end of June indicated that the birds prefer to fly from the colony of De Kreupel in Lake IJsselmeer to the more distant Lake Markermeer. A possible explanation for this behaviour is the relatively low abundance of 1+ smelt in Lake IJsselmeer, or the low attainability of smelt for the common tern.

Smelt caught by the fisherman in Lake Markermeer in August 2011 were low in abundance, but it should be noticed that the location of the hauling was not in the deepest part of the lake. While hauling at a location with 2 m depth, the fisherman explained that smelt was at 4 meters depth. This is backed up by the transparency of the water, which was as clear as 'tap water' (Secchi depth not measured) during the hauling, while smelt prefers turbid water.

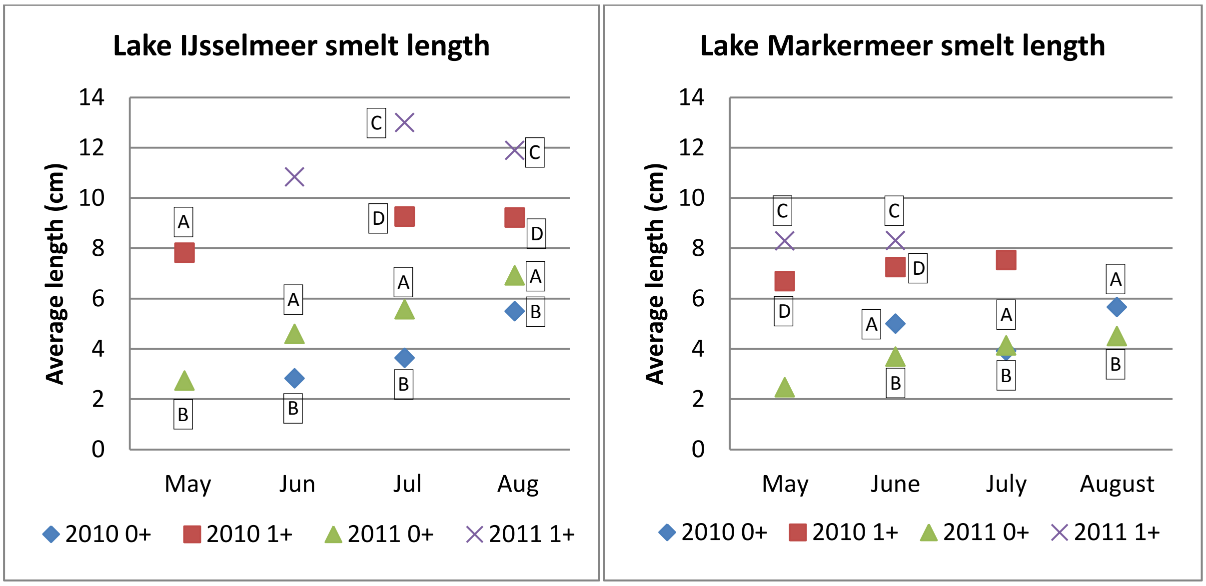


Figure 16. Average lengths of 0+ and 1+ smelt in 2010 and 2011 for Lake IJsselmeer and Lake Markermeer. Smelt in August 2011 in Lake IJsselmeer and Lake Markermeer is caught by fisherman. Different letters (A and B for 0+, C and D for 1+) in proximity of the measurements indicate if the smelt lengths for each age class differ from each other (Mann-Whitney U test with p<0.05)

3.2 Diet of birds

3.2.1 Common tern

In 2010 and 2011, smelt was the most abundant species predated by common tern (Figure 18). Especially 2010 seemed to be a good year for predating on smelt, as high numbers were found in the pellets (Figure 18Figure 19). One month later the proportion of 1+ smelt was found less in the pellets of the terns, and the proportion of smelt dropped considerably (+/- 40%) in numbers and weight (Figure 18 & Figure 19). A possible explanation for this decline could be the high pressure on smelt by avian predation, as this was mentioned by van Eerden *et al.* (1993). As ruffe spawns later in the year than smelt, influx of 0+ fish is later, and was more found in the diet of the common tern at the end of the season.

In 2011 lower numbers of fish were found in the pellets then 2010. However, July 2011 showed a higher average weight per prey compared to July 2010, making the difference in pellet weight between both years smaller (Table 6). The higher individual weight per fish is caused by a shift in prey caught. While in July 2010 mostly ruffe and smelt were caught, in July 2011 a larger proportion of perch (and a smaller proportion of smelt) was caught (Figure 18). Perch (and ruffe) added more weight to the pellet per individual compared to the smaller sized smelt (Figure 19). As smelt is the main food for the nestlings (van den Winden *et al.*, 2009), this shift seems to be not favourable for a successful growth of nestlings in June and July. However, as breeding success was poor in both 2010 and 2011, it is unknown if the relative higher amount of perch had an influence on the breeding success of the common tern.

Pellets collected at the common tern breeding colony of Hoeckelingsdam in western Lake Markermeer displayed a higher proportion in amounts of cyprinids. This contributed to the high average pellet weight of common tern in comparison to their peers on De Kreupel. Cyprinids were in comparison with smelt and other fish heavier in weight and even with a low amount in numbers they contributed highly to the weight of the pellet. The relative high number of smelt (50%) found in the pellets suggested that the common tern in Hoeckelingsdam used Lake Markermeer as forage area. However, this was probably not enough to fulfil the energy demands of the terns and their chicks, as the birds also visited the ditches in Noord-Holland to hunt for cyprinids (Figure 18 and Figure 19).

Table 6. Average weight per pellet compared to the average number of fish per pellet

Date	Location	Number of pellets	Average weight per pellet (gr)	Average number of fish per pellet (#)	Average weight of 1 fish (gr)
07-07-2010	De Kreupel	29	14.9	6.6	2.2
20-08-2010	De Kreupel	98	12.0	7.0	1.7
24-09-2010	De Kreupel	53	16.9	5.9	2.9
05-07-2011	Hoeckelingsdam	35	23.4	2.6	9.0
07-07-2011	De Kreupel	51	12.7	4.1	3.1
14-08-2011	De Kreupel	10	8.4	4.8	1.8

Mean weight was not significantly different between years, months and locations (Kruskal-Wallis =8.619, df=5 and p=0.125, Figure 17). This means that an elderly bird needs around 12.6 grams per day to fulfil his energy demand. However, as breeding success was poor in both 2010 and 2011, not enough preferred food could be collected for the chicks. A probable constraint would be the availability of suitable fish (1+ smelt) in close proximity of the nest in combination with time. Hoeckelingsdam (Lake Markermeer) had large outliers (96 and 120 gr), which contributed to the high average weight (Table 6), but an equal mean weight (Figure 17).
Differences were found for both the mean of average fish per pellet (Kruskal Wallis=39.493, df=5 and p=0.000) and mean of average weight of 1 fish (Kruskal Wallis=78.863, df=5 and p=0.000).

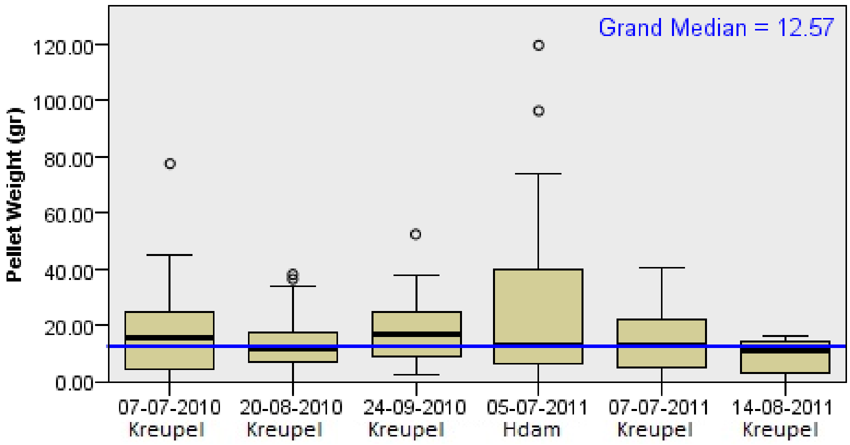


Figure 17. Boxplot with output of the Kruskal-Wallis test of pellet weight with output=8.619 ,df=5 and p=0.125

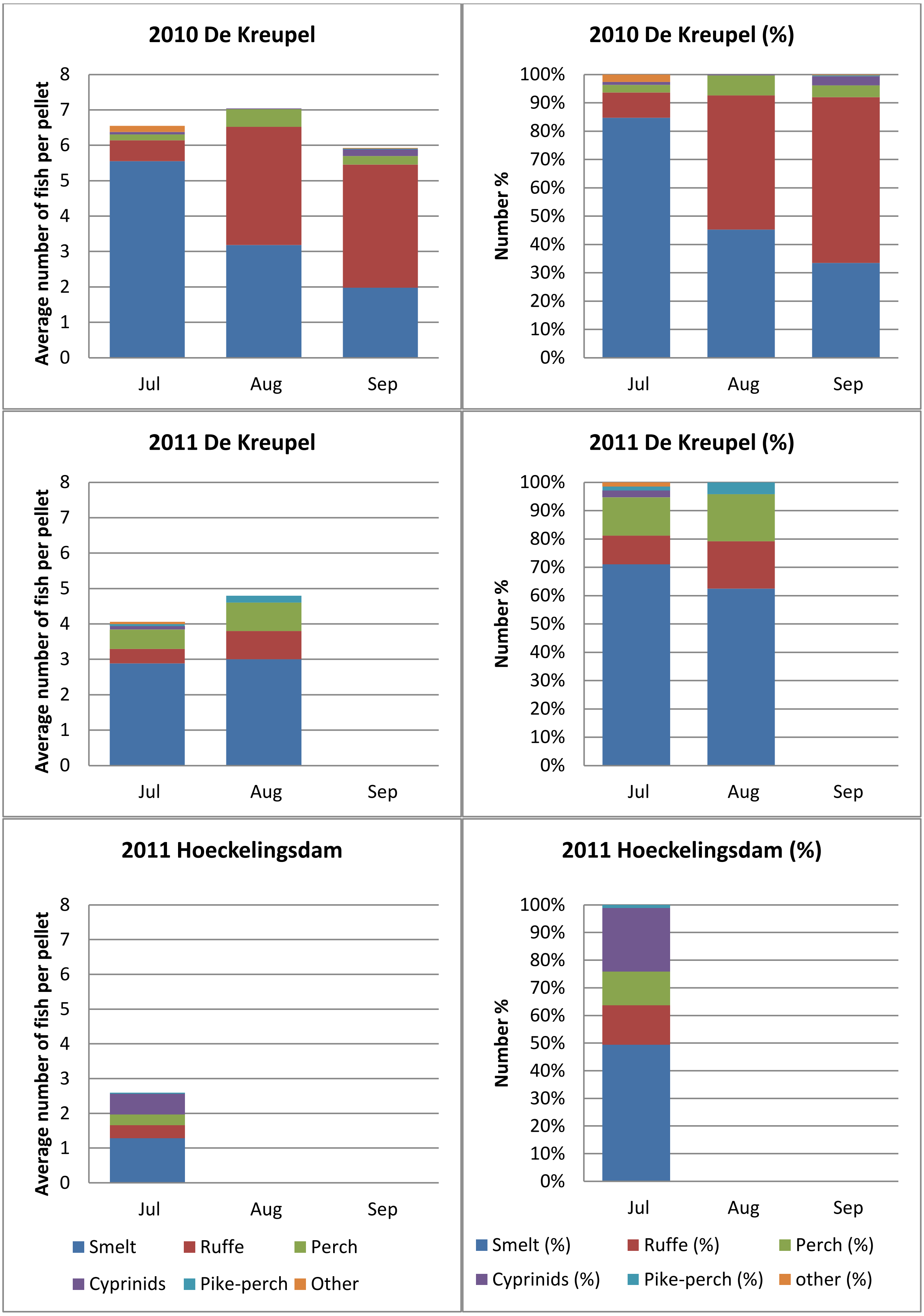


Figure 18. Left: absolute numbers of fish found in the pellets of common tern in 2010 and 2011 for De Kreupel and Hoeckelingsdam, Right: relative percentage of fish found in pellets

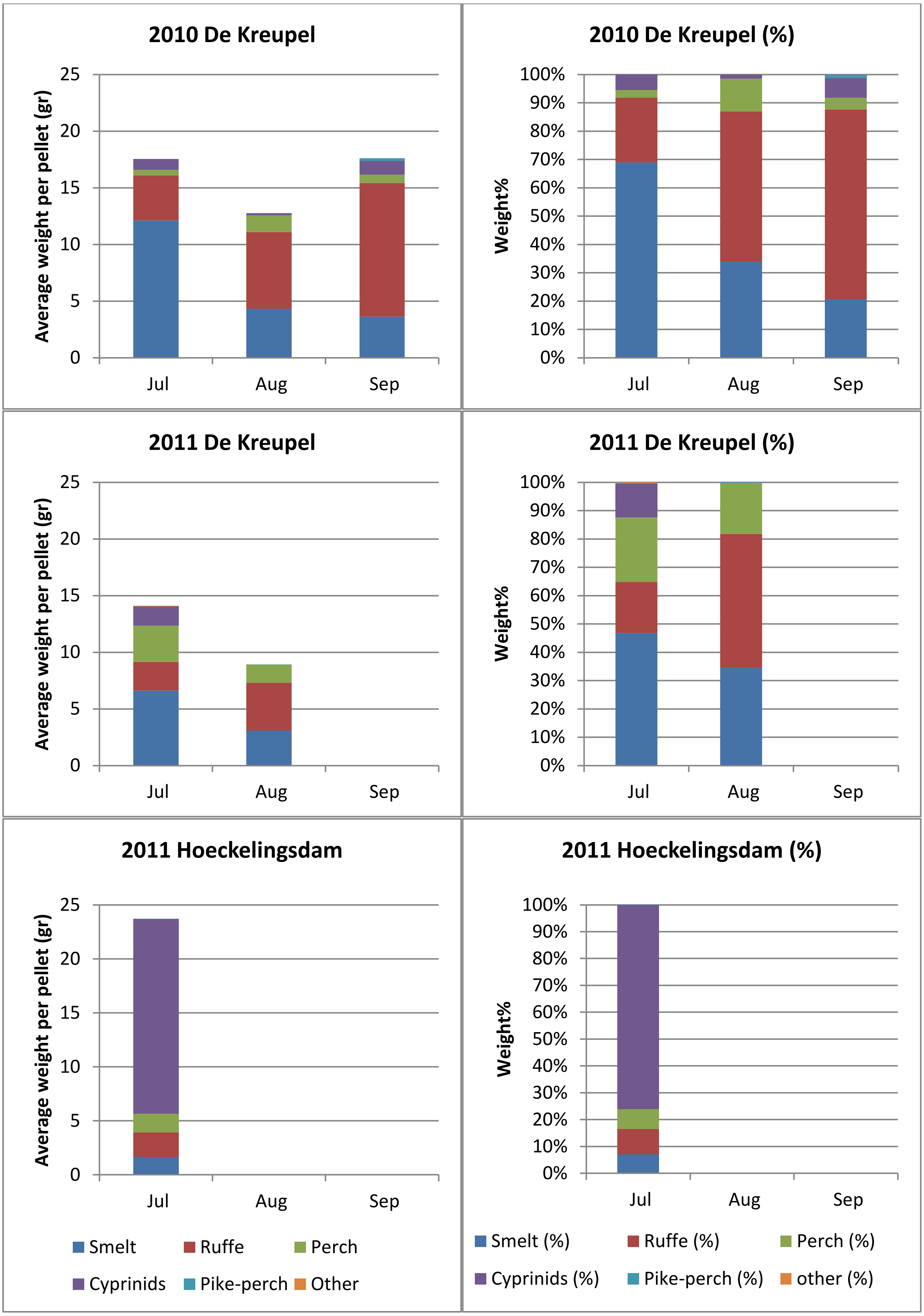


Figure 19. Left: absolute weight of fish found in the pellets of common tern in the 2010 and 2011 for De Kreupel and July 2011 for Hoeckelingsdam, Right: relative percentage of fish found in pellets

In July 2010 the highest number of smelt per pellet was caught. Also the highest amount of 1+ smelt (64%) was caught in the same month (Figure 18 and Figure 20). Later in the season of 2010 significant less 1+ smelt is caught (Kruskal-Wallis test=16.270, df=2, p=0.000, Figure 21). The Mann-Whitney U test shows that the amount of 1+ smelt in the diet of July 2010 differed significantly from August and September 2010. The amount of 1+ smelt decreased in the latter months to maximum 23%. This is partly attributable to avian predation pressure on 1+ smelt and the growth of 0+ smelt to comparable sizes as 1+ smelt in the beginning of the season.
In July 2011 the same proportion of 1+ smelt was caught, almost equal to July 2010 (64% in 2010, 61% in 2011, Figure 20). The average number of smelt per pellet was lower (5.5 in 2010 vs. 2.8 in 2011). The high transparency levels in Lake IJsselmeer in the first half of the common tern season of 2011 could have influenced the smelt attainability or availability for the terns (more in paragraph 3.3.1). The transparency levels found with the Secchi-disc are all in the intermediate transparency region (0.4-1m) of the cormorant (van Rijn & van Eerden, 2002). So transparency levels could influence position of smelt in the vertical water column (more in paragraph 3.3.1).

A significant difference is found in the amount of 1+ smelt between Hoeckelingsdam and De Kreupel (Kruskal-Wallis test=8.967, df=2, p=0.011, Figure 22). This is attributable the differences between De Kreupel and Hoeckelingsdam. The amount of 1+ smelt caught does not differ between July and August 2011 for the birds on De Kreupel (Mann-Whitney U test=167.500, p=0.070). With the higher amounts of smelt and lower transparency levels on Lake Markermeer (Figure 26 and discussed in paragraph 3.3.1), smelt should be more attainable for the terns. This is supported as individuals of De Kreupel were seen flying to the Lake Markermeer and back to De Kreupel with smelt in their beak. As is assumed that fish in Lake Markermeer are homogeneously distributed, and water transparency in June 2011 in Lake Markermeer is the same and the amount of smelt caught in the various parts of the lake is about the same size, another factor is influencing the attainability of smelt for the common tern Hoeckelingsdam. The north side of the Lake Markermeer is beyond the forage range of the common tern of Hoeckelingsdam, which is according to Pearson (1986) 13.6 mile (=22km). According to Cramp (1985), forage range is maximal 37 km. Becker *et al*. (1993) shows the same values (26-30 km) with a mean radius of only 6.3 km. A possible explanation is the recreation and shipping (Vaargeul Amsterdam-Lemmer) in the area around Hoeckelingsdam, whereas around Houtribdijk hardly any recreation exists and focus is on nature (de Jonge, 2008). The recreation and shipping activities could influence the position of smelt or the behaviour of foraging birds. However, it is also possible that Lake Markermeer is not as homogeneously distributed as is expected.

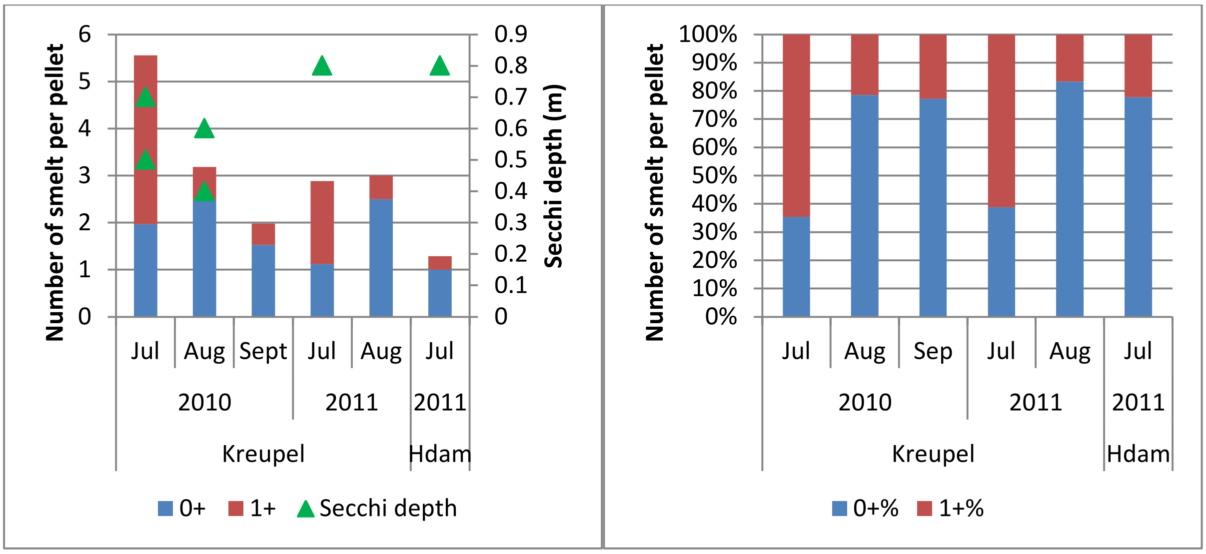


Figure 20. Left side: Numbers of 0+ and 1+ smelt caught divided by the amount of pellets of common tern on De Kreupel for 2010 and 2011 and for Hoeckelingsdam in July 2011 (Hdam) based on numbers, with the measurements of transparency in Secchi-depth (right axis), Right side: idem relative (%).

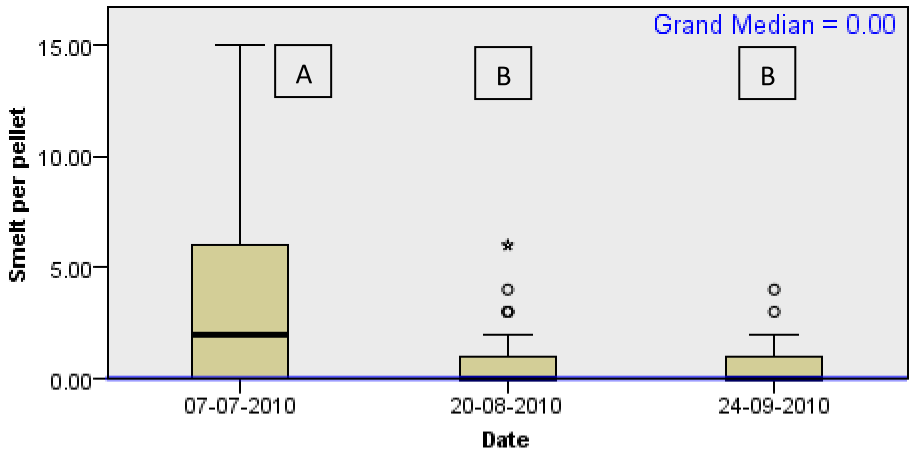


Figure 21. Boxplot of the Kruskal-Wallis test of the number of 1+ smelt per pellet of common tern on De Kreupel in 2010 with output=16.270, df=2, p=0.000. Different letters indicate if the 1+ smelt per pellet differ from each other (Mann-Whitney U test with p<0.05)

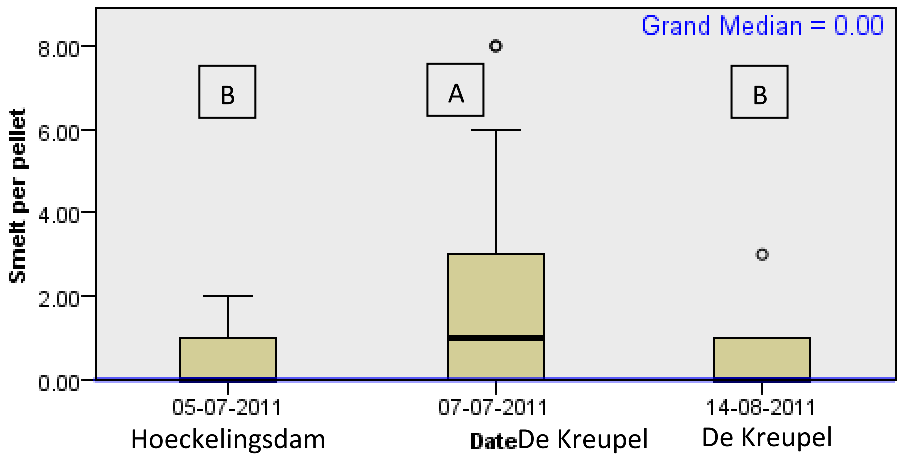


Figure 22. Boxplot of the Kruskal-Wallis test of the number of 1+ smelt per pellet of common tern on De Kreupel in July and August 2011 and Hoeckelingsdam in July 2011 with output=8.967, df=2, p=0.011. Different letters indicate if the 1+ smelt per pellet differ from each other (Mann-Whitney U test with p<0.05)

When comparing the proportion of 0+ and 1+ smelt based on weight (Figure 23), 1+ smelt shows a larger proportion (in weight) compared to the proportion based on numbers (Figure 20). This enhances the fact that 1+ smelt is important as a food source for the common tern. At the end of the common season the proportion of 0+ smelt increases, as smelt is growing, gaining more weight. This is seen in 2010, where the number of 0+ smelt in September is lower compared to July and August (Figure 20 left side), but weight is higher (Figure 23). This is also visible in 2011.

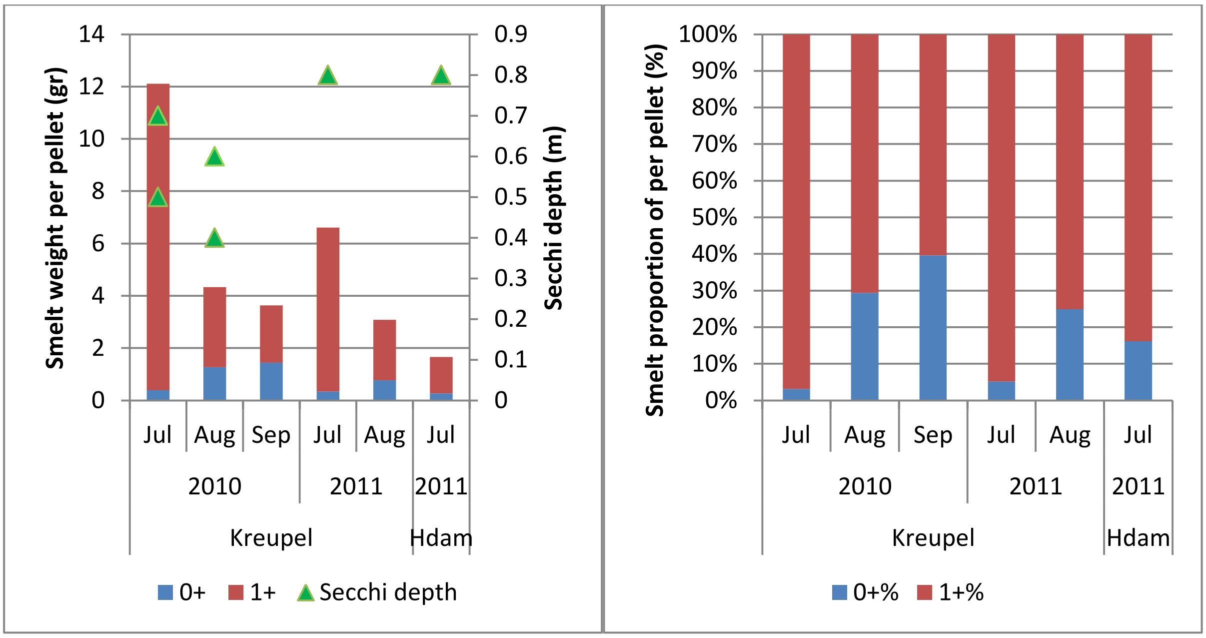


Figure 23. Biomass of 0+ and 1+ smelt caught divided by the amount of pellets of common tern on De Kreupel for 2010 and 2011 and for Hoeckelingsdam in July 2011 (Hdam), with the measurements of transparency in Secchi-depth (right axis), Right side: idem relative (%)

The length of the smelts found in the diet of the common tern do differ in July 2010 and 2011 for Lake IJsselmeer for both 0+ (Mann-Whitney U test=2.435.000, p=0.000) and 1+ (Mann-Whitney U test=10.463, p=0.001) smelt. One month later, the differences still exists for 0+ smelt (Mann-Whitney U test=1.335.500, p=0.00), but not for 1+ smelt (Mann-Whitney U test=156.000, p=0.813). There seems to be a closer gap between lengths in the different years compared to the lengths acquired form the boat hauls. Length differences between common tern, cormorant and with the boat hauls are further discussed in paragraph 3.4.

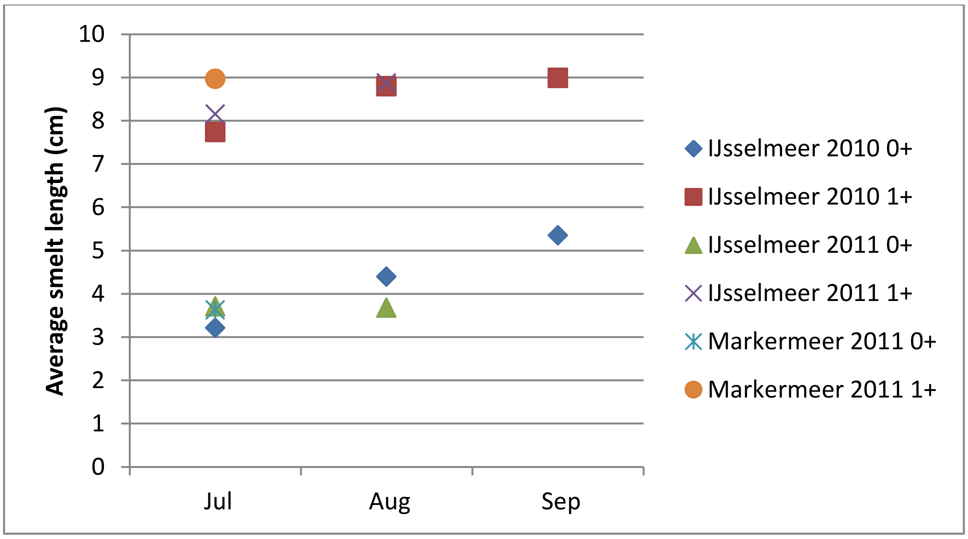


Figure 24. Average lengths of 0+ and 1+ smelt found in common tern pellets in 2010 and 2011

3.2.2 Common tern vs. cormorant

Common tern seemed to predate on 0+ and 1+ smelt while the cormorant mainly predated on 1+ smelt (Figure 25). 1+ smelt is in July important for the almost full-grown fledglings of the common tern. However, 0+ was also predated as an alternative for the low abundance of 1+ in the top layer in the water column, whereas the cormorant uses the total water column and did not hunt for 0+ fish. In September the roles were reversed, while the cormorant generally predated on the 0+ year class, common tern now predated also on the 1+ class. At these times all nestlings have flown out, 0+ smelt has reached more suitable lengths and the common tern can focus on searching food and prepare for the migration. Cormorant also finished breeding, but as an opportunistic animal it does not rely on smelt as much as the common tern does. (van Rijn & van Eerden 2002).

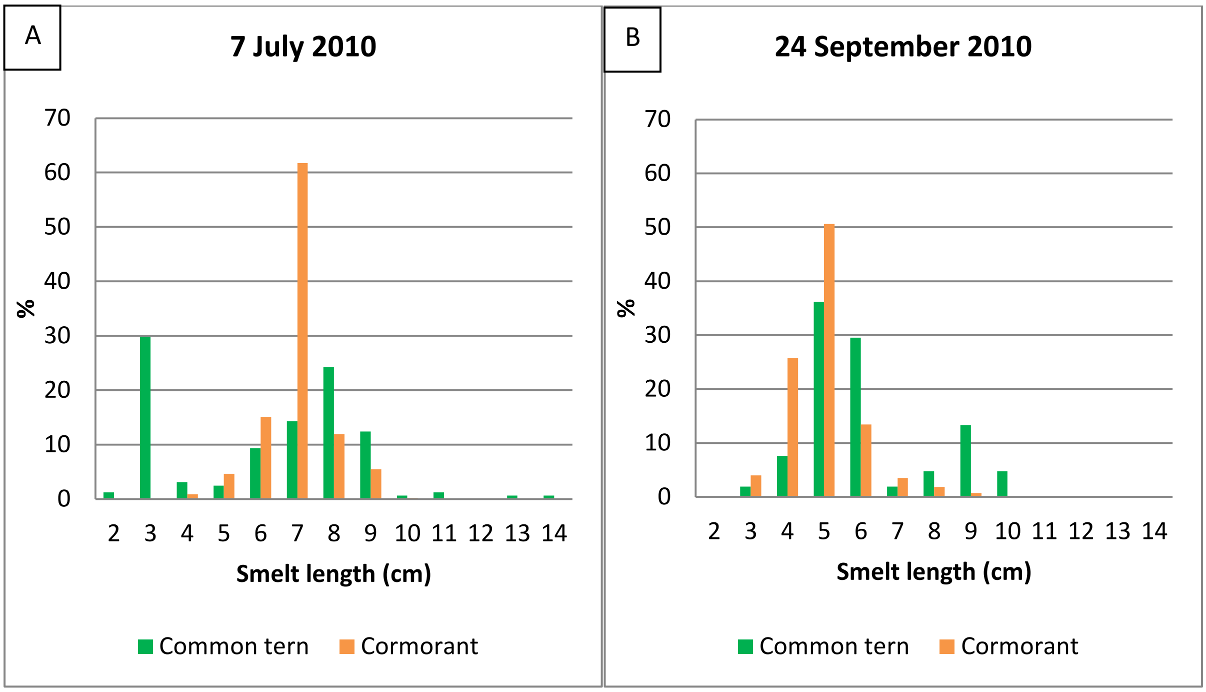


Figure 25. Smelt lengths found in the pellets of common stern (green) of De Kreupel and cormorant (orange) of De Kreupel during months that pellets of both species were collected in the Lake IJsselmeer area: 07 July 2010 (A) and 24 September 2010 (B). For 7 July and 24 September two peaks (0+ and 1+ smelt) are visible in the diet of the common tern. Division of both year classes is in between those peaks. The cormorant mainly predated on one year class

3.3 Attainability

3.3.1 Transparency

Transparency is a very important factor for a successful hunt for the piscivorous birds. For cormorants an intermediate transparency of 40-100 cm is preferred (van Rijn & van Eerden 2002). In 2010 transparency was at the low end of this intermediate transparency (Figure 26). Lake IJsselmeer reached a higher value compared to Lake Markermeer in July and August, but the difference is not large.

In 2011 water clarity was higher in Lake IJsselmeer in the first part of the common tern season. Water transparency reached a maximum value of 2 m in May. Values dropped beneath 1 meter Secchi depth in July. Lake Markermeer reached values between 50 and 100 cm during the whole common tern season (Figure 26). As “smelt concentrates near the surface when the water is turbid (Secchi-depth = 0.5) and near the bottom with clearer water (Secchi depth = 1.2m)” (De Graaf & Keller 2010), common terns had less chance to prey on smelt in 2011 in Lake IJsselmeer compared to 2010 (Figure 20). Terns had to resort to other or bigger fish. As the small nestlings cannot consume large fish, they will reject the prey brought by the parents and may starve of food deficiency. As Lake Markermeer has a transparency lower than 1 m, smelt shows less light avoiding behaviour.

Combined with the high abundance of smelt, compared to Lake IJsselmeer (Figure 14), Lake Markermeer could be a more suitable forage area for the common tern in May and June. This fact was supported during the field trip in Enkhuizen de Ven on 30 June, where the common terns with prey in their beak were passing by on the way to De Kreupel.

For cormorants it is known that they prefer an intermediate transparency of 40-100 cm to hunt successfully (van Rijn & van Eerden 2002). As a plunge-diver the transparency for the common tern should be lower in order to catch smelt. As smelt swims close to the bottom on the lake at 1m it is still reachable for the cormorant, but unreachable for the tern.

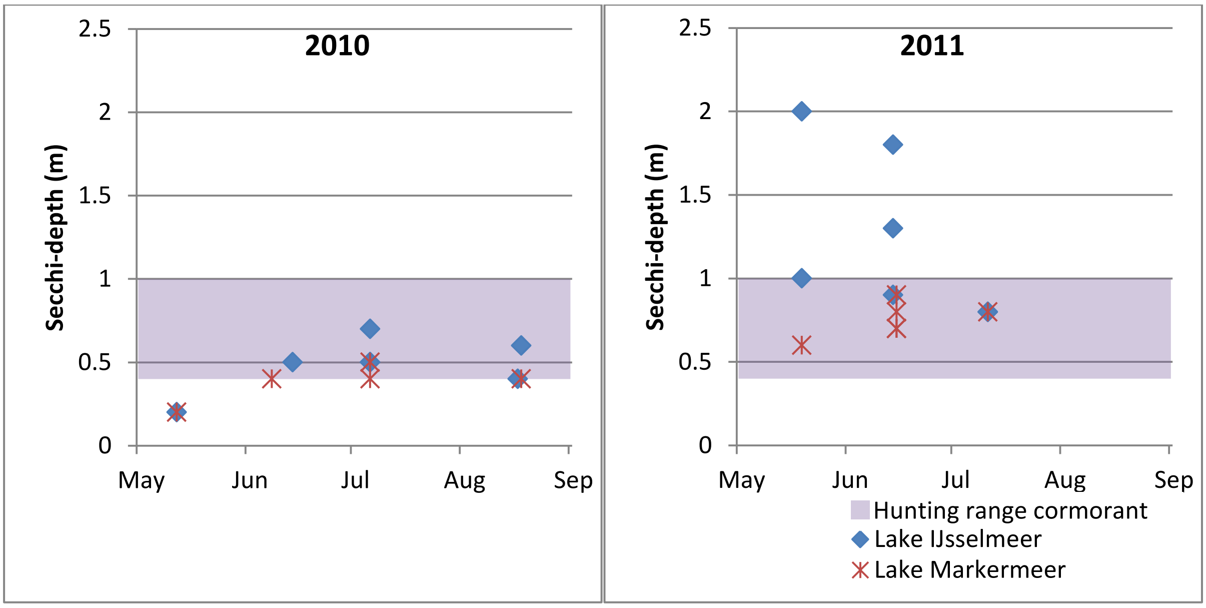


Figure 26. Left: Secchi-depths and the hunting range for cormorant for Lake IJsselmeer and Lake Markermeer in 2010, right: idem for 2011

3.3.2 24-hour measurement

In May birds could not be properly determined and counted, as the distance to De Kreupel was too large. The birds mainly foraged on the other side of the island. As most birds also flew above the island, it was difficult to determine if the bird was foraging on the water or landing on the island. The birds above the island were not counted towards foraging birds (and not shown in the graph). Also the inexperience of the observer watching birds on a moving vessel played a role in recognizing birds and behaviour. Due to this only estimations and an overall impression of behaviour of tern-like birds (mainly common tern with black headed gull) is given in May. Still some overall comments could be made for the plunge-diving birds.
In May, as nestlings are not present and breeding just started or is yet to start, all time could be spent by searching for food and catching fish for the courtship. Numbers of plunge-diving birds were relatively low. In the evening these numbers increased. Around 20.45 till 21.40 birds were flying towards De Kreupel to rest for the night. This continued until after 22.00, when numbers of incoming birds dropped and it became too dark observe birds. The observed peak (in Figure 27) was probably caused by the incoming birds foraging farther away from De Kreupel. When flying towards De Kreupel, still signs of foraging were detected. Sunrise was on 11 May at 05.53. One hour later considerable bird numbers started to forage. This went up till around 10.00, when 3000 birds foraged on the water. Numbers dropped around 11.00 to less than 1000. Probably the area around De Kreupel was not suitable for the common tern. When not counting incoming and outgoing birds, numbers were less than 1000 individuals (Figure 27). Numbers of foraging common tern on 15 august remained less than 20 (Figure 28). No influx was observed of birds flying and foraging towards De Kreupel around sunset. Black tern numbers averaged between 170 and 500. In the

evening, black tern started to fly in the direction of De Kreupel. Near sunset, the birds were moving towards De Kreupel to get ready for the night. Some of them still showed foraging behaviour. After sunset, foraging activities stopped (Figure 28) and more than 10.000 black terns could be seen flying (without foraging) towards the island. Sunrise was on 17 August at 06.27. Only one hour later more than 50 common tern started to forage. The black tern was already foraging just after sunrise. Numbers of black tern increases more consistently, in comparison to the common tern. Larger numbers were spotted one hour after sunrise.

Based both 24-measurements it seems that the common tern does not show behaviour to hunt around sunset and sunrise, when smelt in the lake was expected to be distributed more evenly in the water column and partly closer to the surface. This pattern of vertical distribution, which was found in 2004, was not confirmed by the fish sampling during this experiment, that seemed to indicate more or less even distribution over the water column during night and day and concentration in the mid layers during dusk and dawn (Mous *et al*., 2004).
During both 24-hour measurements common terns started to forage one hour after sunset. In May it seemed that birds foraged around sunset, but as the boat catches did not show high amounts of smelt catches, forage activities by birds were low and the high numbers were probably caused by other bird movements above the island itself. Black tern showed different patterns then common tern, but the black tern is more specialized to insects (mosquitoes), which mainly fly out in the evening (own observation in May). Black tern utilised this peak in insects and hunted around these times, and thus showing a different pattern compared to the common tern.

During the August experiment common and black terns were not seen plunge-diving for fish around the boat. Black terns were foraging but all seemed to pick up very small prey from the surface. Only when social groups of cormorants were fishing in the surroundings, usually at a greater distance from the boat, there was concentrated activity of gulls and terns in association.

Table 7. Sunrise and sunset times

Date	Sunrise	Sunset
09/05/2011		21.17
11/05/2011	05.53	
15/08/2011		21.05
17/08/2011	06.27	

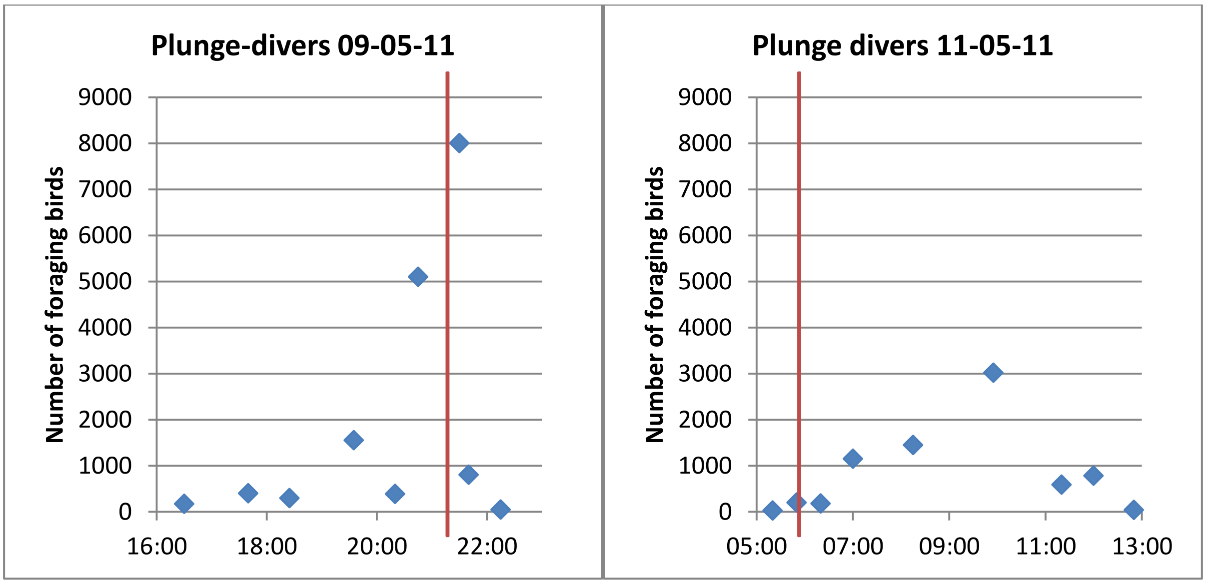


Figure 27. Number of foraging plunge-diving birds during the 24-hours experiment in May. The red lines indicate sundown or sunset times

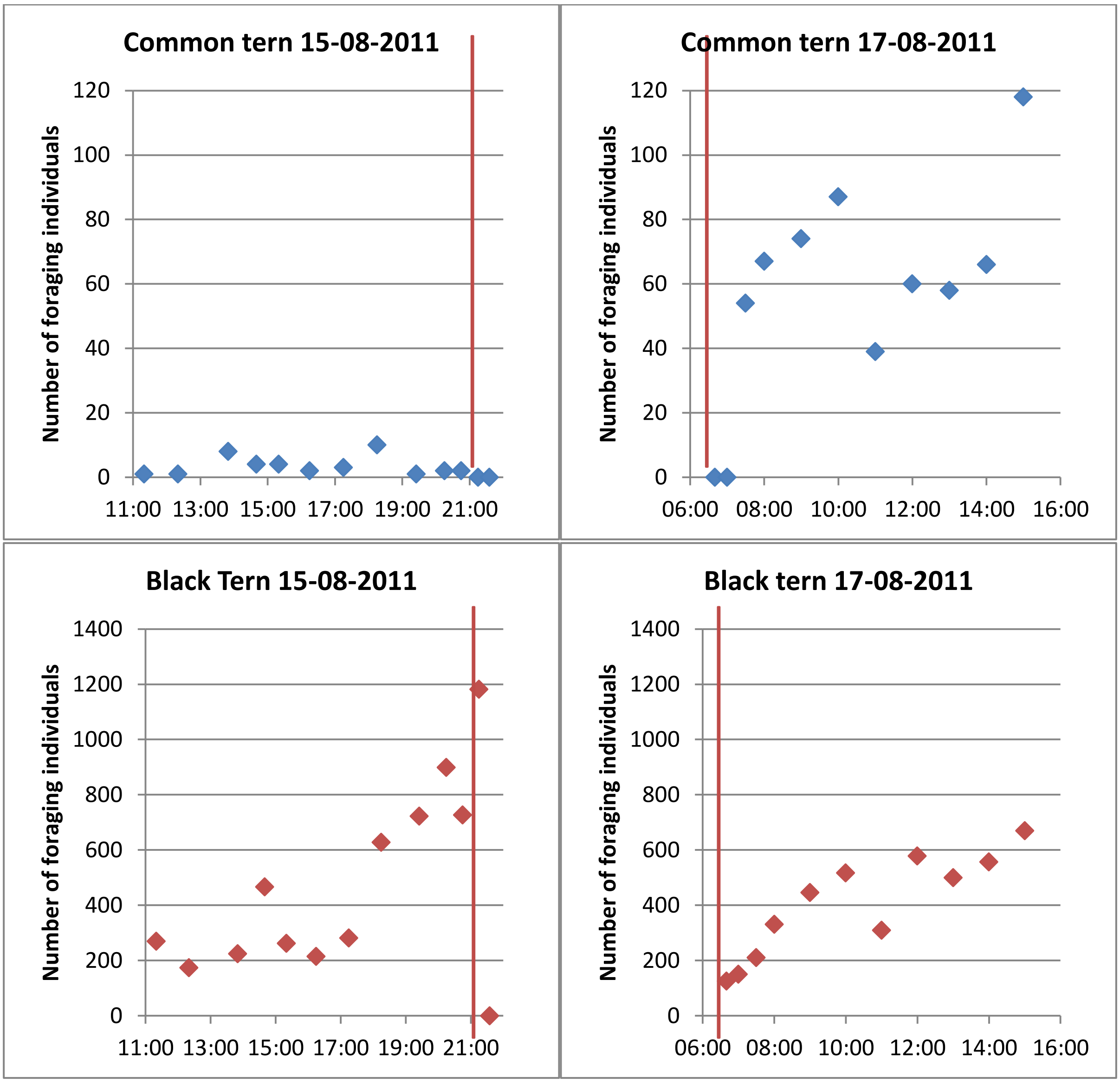


Figure 28. Number of foraging common tern and black tern during the 24-hour experiment in August. The red lines indicate sundown or sunset times

3.4 Smelt length in boat hauls and pellets

When comparing the average smelt lengths of the boat hauls and those found in the pellets of the common tern, significant differences were found in 2010 and in 2011. For all cases, except June 2010 0+ smelt Lake Markermeer, the lengths of smelt found in the pellets of the common tern were smaller compared to the smelt caught with the boat (Mann-Whitney U test, $p<0.05$, Figure 29 & Figure 30, Annex 3). To repeat the fact that common tern only catch fish in the top layer of the water column and the boat catches (and cormorant) reach the whole water column, these results suggest that as 0+ and 1+ smelt increase in size, the fish tends to swim deeper in the water column (or they swim faster and are harder to catch that way, or the terns show positive selection for smaller smelt). This was also found in Lake Victoria, East Africa. During daytime zooplanktivorous adult fish dwelled near the bottom, while juveniles stayed closer to the surface (Goudswaard *et al*., 2003). However, this cannot explain the longer length of 0+ and 1+ smelt caught by the common tern in September 2010 compared to the cormorant (Figure 25). This could be from to the fact that other fish were more interesting for the cormorant or that transparency levels changed in favour of the tern.

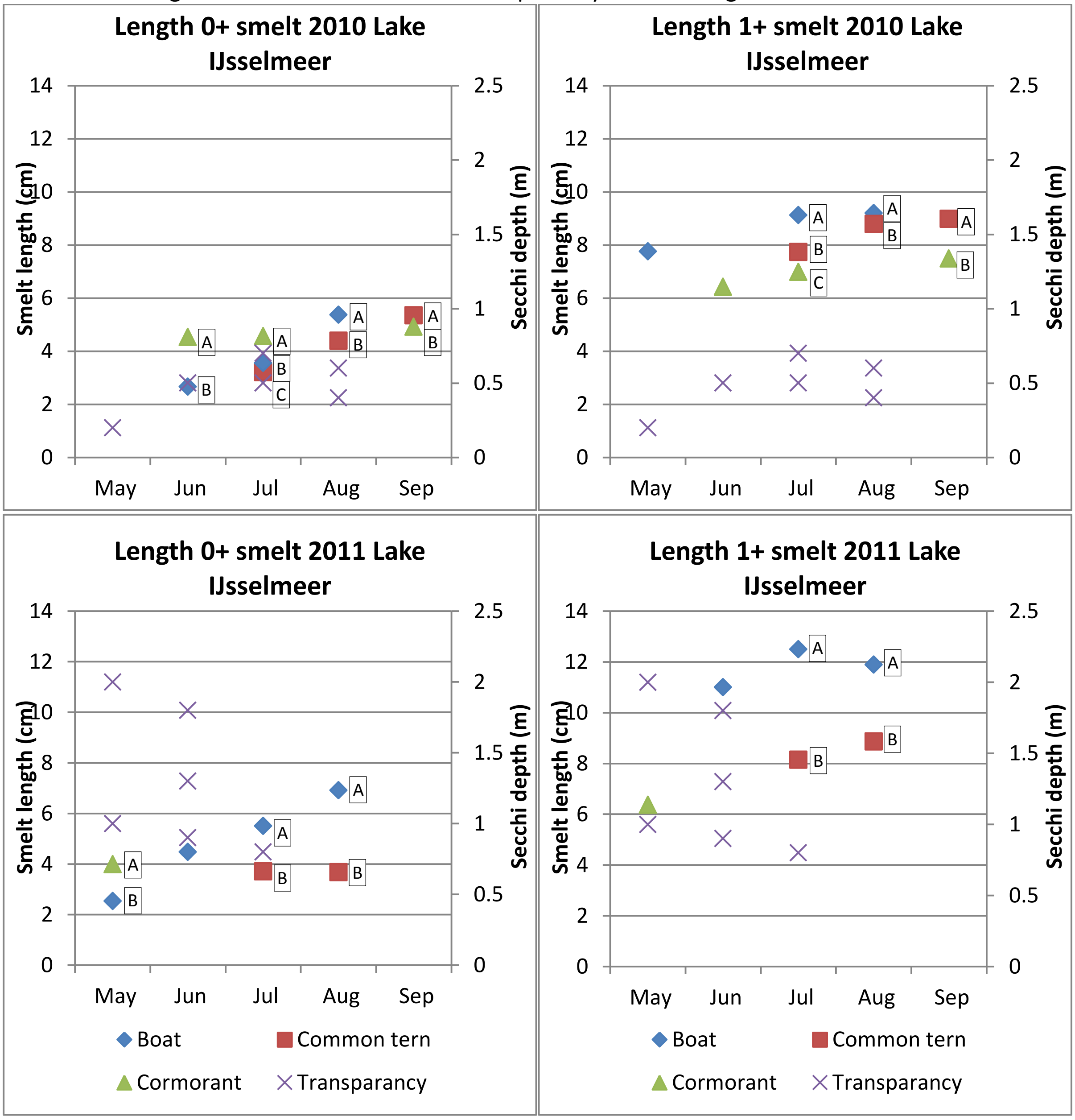


Figure 29. Average length of 1+ and 0+ smelt caught with the boat catches and predated by common tern and cormorant in Lake IJsselmeer with the transparency (right axis). Different letters on the right side of the measurements indicate if the methods differ from each other (Mann-Whitney U test with p<0.05)

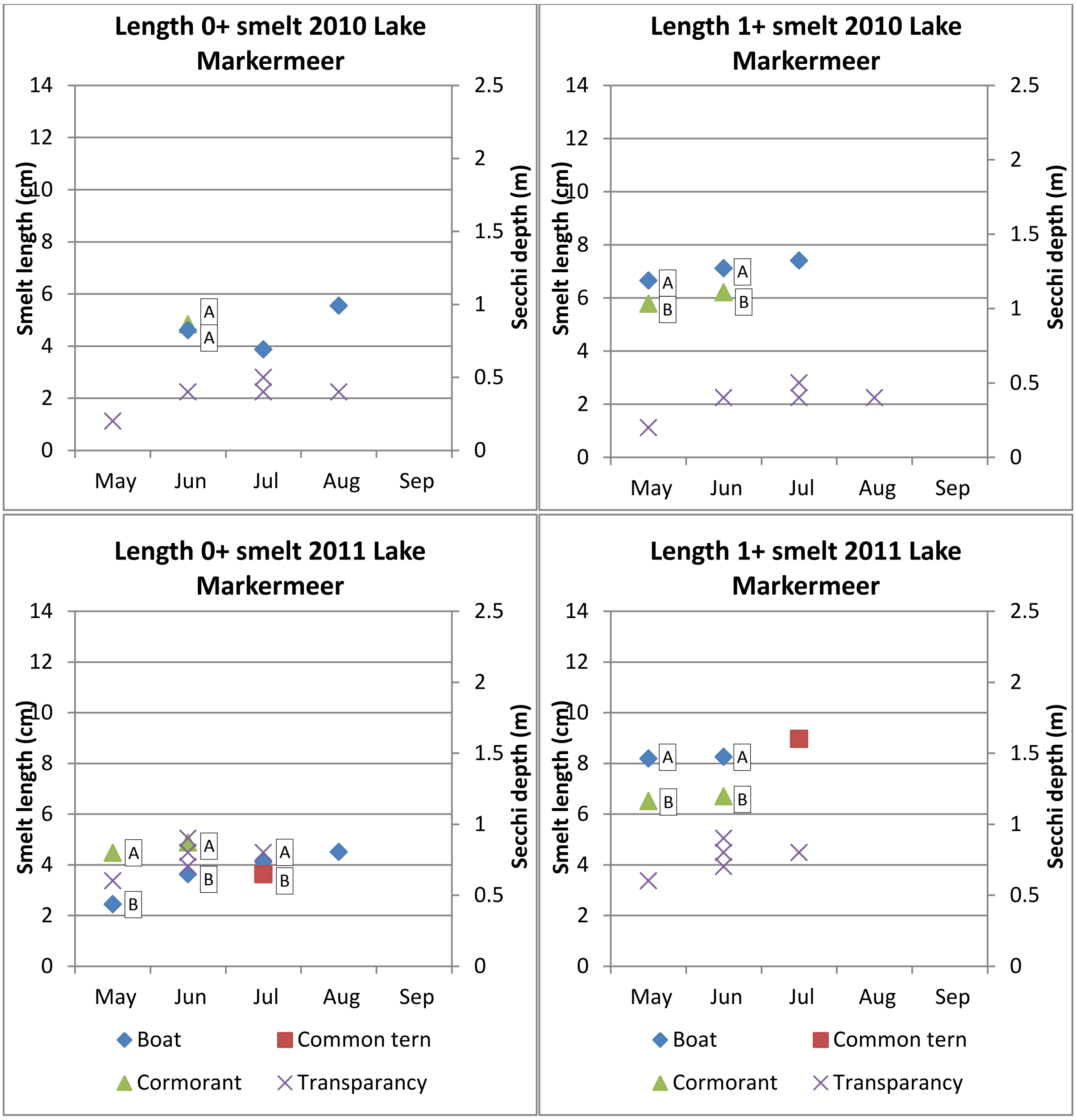


Figure 30. Average length of 1+ and 0+ smelt caught with the boat catches and predated by common tern and cormorant in Lake Markermeer with the transparency (right axis). Different letters on the right side of the measurements indicate if the methods differ from each other (Mann-Whitney U test with p<0.05)

3.5 Proportion of 0+ and 1+ smelt in boat hauls and pellets

Boat hauls always had the lowest amount of 1+ smelt (Figure 31, except Lake Markermeer June 2010, Figure 32). This supports the idea that 1+ smelt is important for waterfowl and that birds actively search for 1+ smelt. However, as explained in paragraph 3.1, bigger fish have more chance to escape the net; the proportion of 1+ smelt of the boat catches could be underestimated. For common tern, 1+ smelt is especially important in July, at the time the chicks are growing and need to be fed. This result seems to match with the results from van den Winden *et al.* (2009), where 1+ smelt was also an important food source for the common tern on De Kreupel in the chick feeding period.

The proportion of 1+ smelt was larger in the diet of the cormorant then in common tern. This suggests that the largest proportion of 1+ smelt was swimming deeper in the water column, out of reach of the common tern (Figure 31). But, as a larger bird, cormorant could also select to leave the small fish aside in favour of the bigger fish. Cormorant also has no preference towards smelt, switching to a different fish species as large smelt becomes scarce.

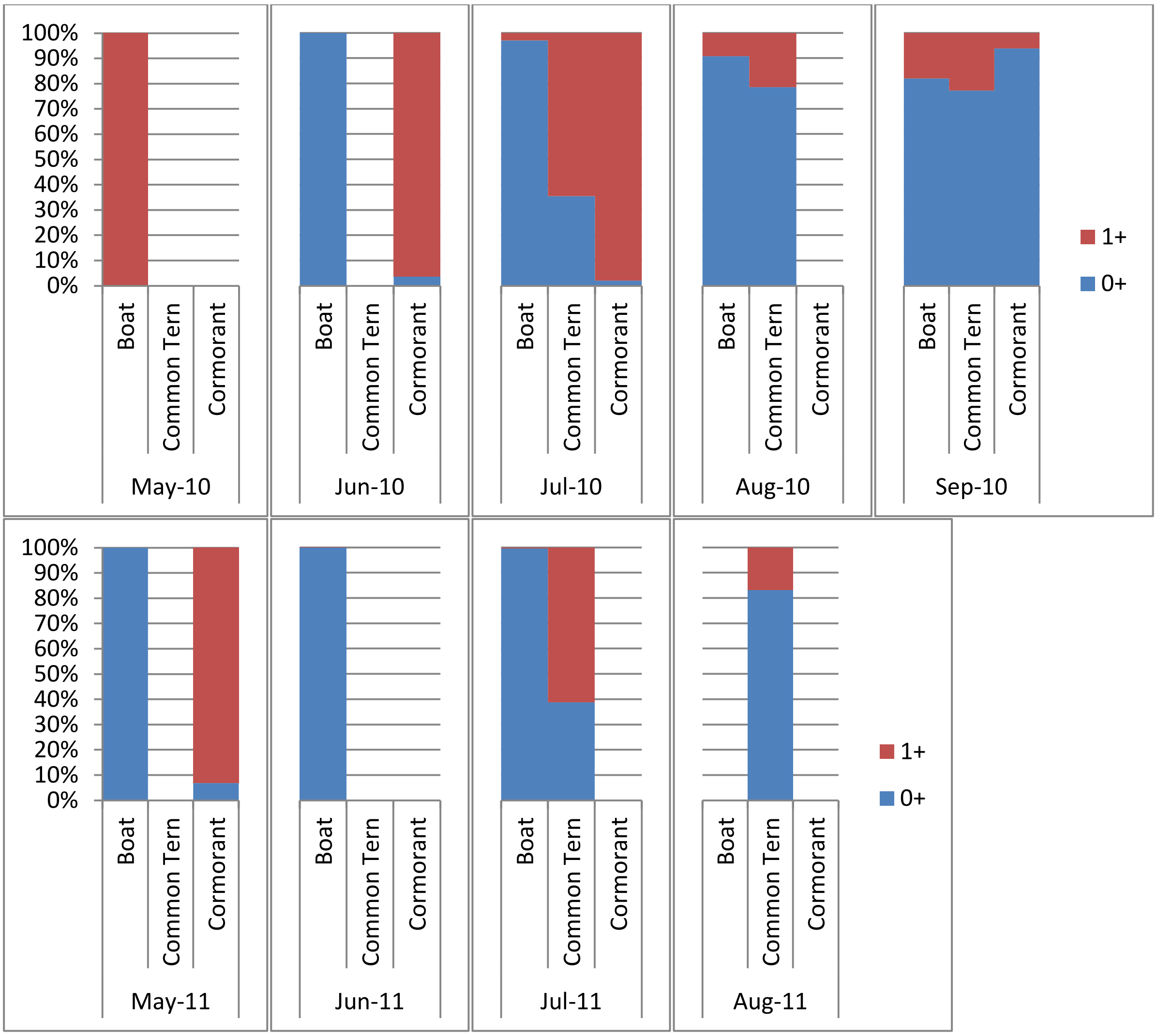


Figure 31. Relative number of 0+ and 1+ smelt caught with the boat and found in the diet of the cormorant and the common tern

For Lake Markermeer only in July 2011 data for the common tern was collected. More data was available for cormorant and it follows the same pattern as in the Lake IJsselmeer. Boat catches had the lowest proportion of 1+ smelt where cormorant had a higher proportion (Figure 32). An exception is June 2010. Here the length of the smelt caught by the cormorant was in between the length of 0+ and 1+ smelt of the boat catches, making distinction difficult.

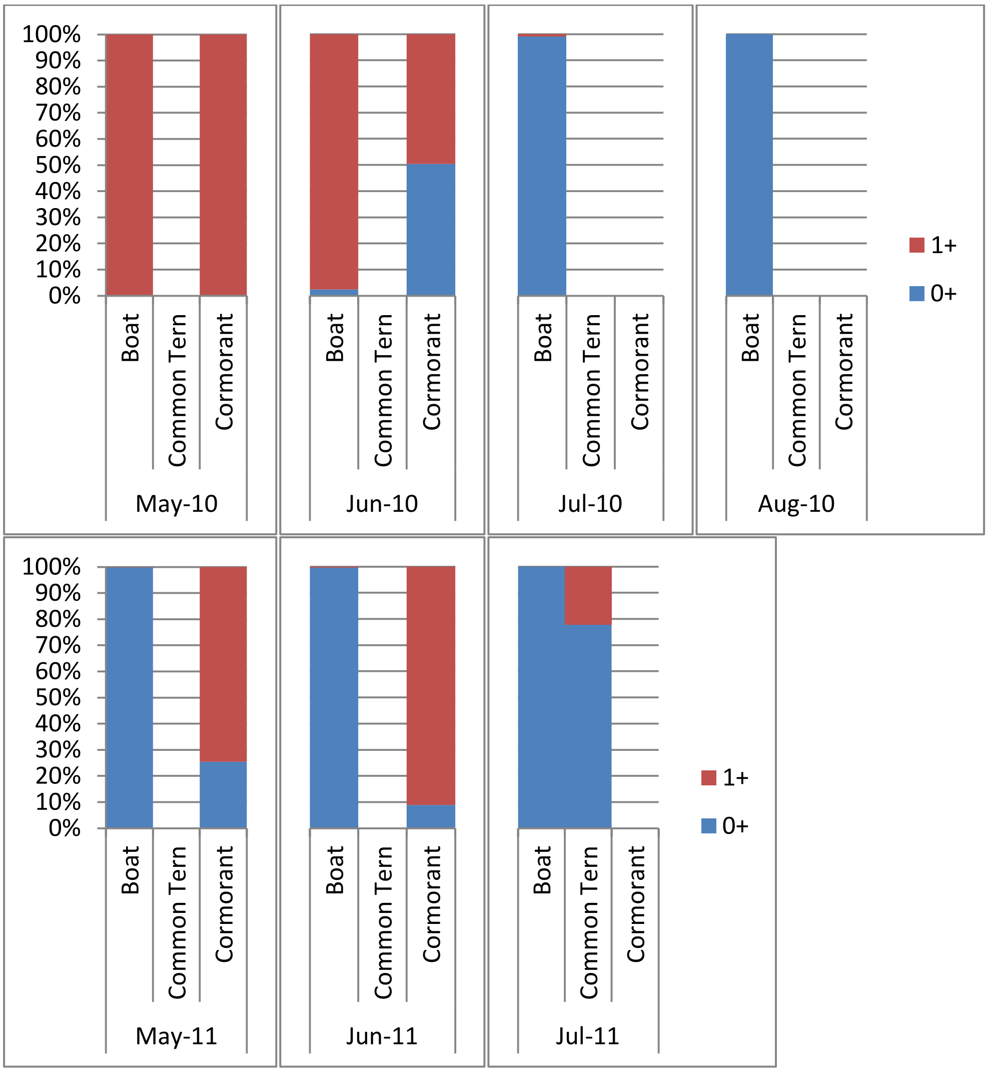


Figure 32. Relative number of 0+ and 1+ smelt caught with the boat and found in the diet of the populations of cormorant and the common tern (Hoeckelingsdam) in Lake Markermeer

3.6 Length-weight relation

Figure 33 shows that the second formula (Fishbase, 2004) was closer to the actual weight of the smelt. Figure 34 shows that the fit of the formula to the actual length-weight with the second formula from 2009 is very close. The formula from 1988 shows an underestimation, especially visible with increasing length. Based on this the weight of smelt seemed to have increased compared to smelt in 1988, when the first formula was documented. This could indicate that the food quality (zooplankton) has increased, while at the same time numbers decreased. This results in a lower stock of smelt, but an increase in condition of the individual fish.

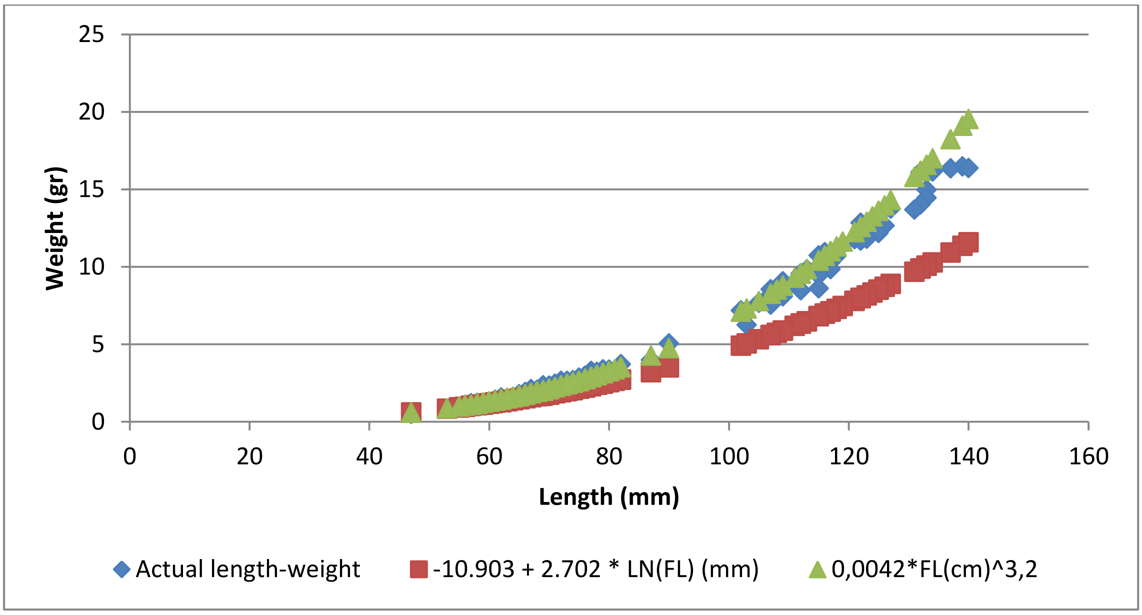


Figure 33. Length-weight relation of smelt: measured length-weight and calculated with two formulas

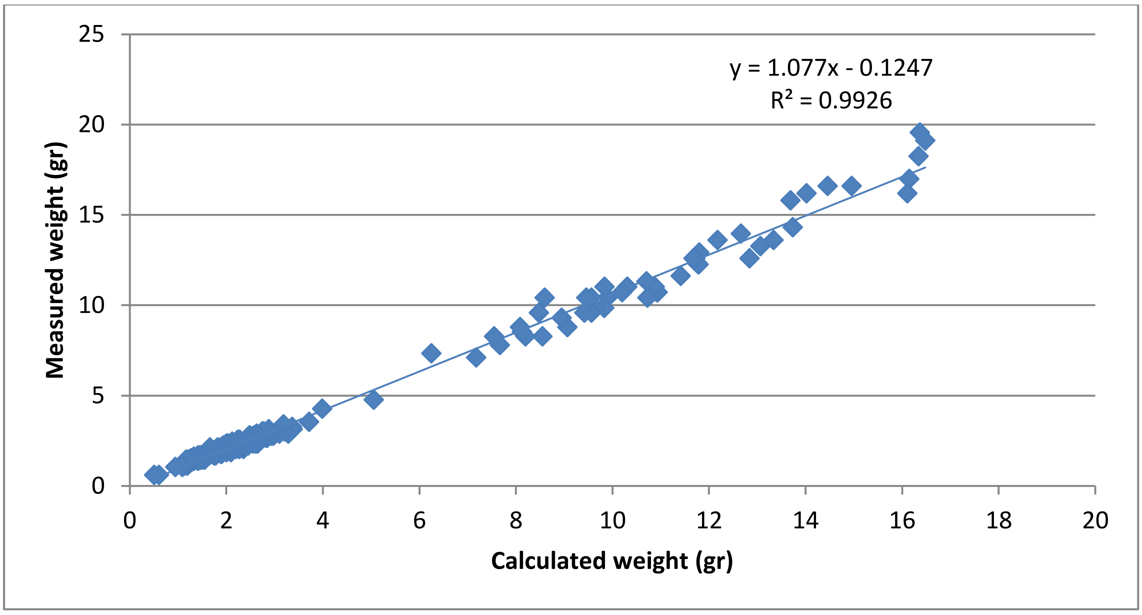


Figure 34. Fit of the formula Fish weight = 0,0042 Fish length (cm)^3,2 to the measured weight*

3.7 Predation of ruffe on smelt eggs

At the location Houtribdijk in Lake Markermeer spawning of smelt occurred. Large quantities of smelt were caught in the fyke nets. On the nets itself large quantities of smelt eggs were deposited. When emptying the contents of the fyke nets in buckets, one individual ruffe had smelt eggs in his beak. On the other locations no spawning was observed. Only ruffe, perch and pike-perch were caught.

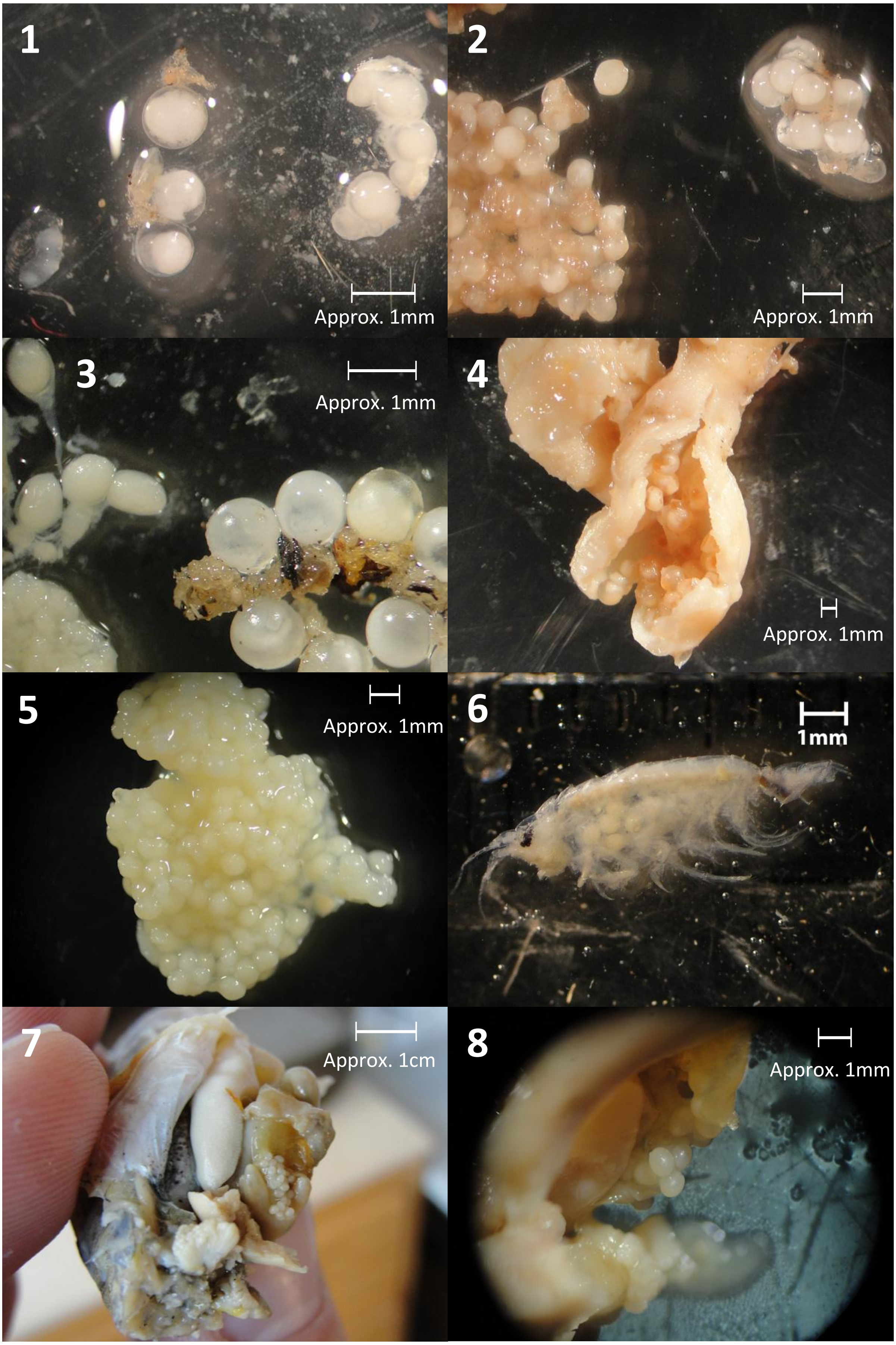
From the stomachs of the ruffe examined in the lab, ruffe predated mainly on Chironomidae and Gammaridae (Table 8). Egg-like shapes were also found in the stomachs (e.g. Figure 35.4). Pictures taken through the binocular could not make clear if the ruffe predated on smelt eggs (Figure 35, pers. comm. Molenaar, 2011). It could be possible that smelt eggs consumed by ruffe visually change compared to the smelt eggs deposited on the nets. It is also possible that the eggs came from Gammarids; in one individual Gammarid eggs were observed (Figure 35.6). Ruffe eggs (Figure 35.5) and smelt eggs also show some similarity. However, ruffe spawns later in the season (Ogle, 1998) and eggs were not developed fully in the female fish. It was clear that the shapes were not parasite eggs (pers. comm. Haenen, 2011). Egg-like prey was mainly predated in Andijk and Flevocentrale. Ruffe caught in Houtribdijk did not predate much on egg-like prey, only three out of fifteen stomachs contained eggs. The ruffe caught in the fyke nets of Flevocentrale contained the highest amount of eggs. This is surprising, as the water was so clear that the bottom of the lake was visible (+/- 2m). As smelt prefers more turbid water, it was expected that smelt avoided this location.

Table 8. Determined species found in the stomach of ruffe. In between brackets the number of individual ruffe with egg-like prey found in their stomach

Location **Date**	Andijk 30/03/2011	Flevocentrale 25/03/2011	Houtribdijk 25/03/2011	Vrouwezand 25/03/2011	Vrouwezand 30/03/2011
Number of Ruffe	20	28	15	9	31
Species in stomach					
Chironomidae	103	44	8	31	136
Gammaridae	116	52	31	56	106
Shrimp	1	0	0	0	2
Egg- like prey (various/unknown)	165 (8)	238 (8)	37 (3)	0 (0)	28 (4)
Unknown (various)	2	17	54	3	5
Total	**387**	**351**	**130**	**90**	**277**

As only for this inventory only two moments immediately after each other are performed, timing could be mismatched with the spawning. Especially with the early influx of 0+ smelt in 2011, eggs could already have hatched before the inventory was carried out. However, Lake Markermeer 0+ smelt had comparable sizes as smelt in Lake IJsselmeer (Figure 16). A more plausible explanation for the failing to observe spawning smelt is the incorrect placement of the fyke nets. At the location in the Lake Markermeer smelt spawning was observed, fykes were positioned close to the dike itself. The dike itself consists out of hard substrate, a favoured spawning setting for smelt. The location of Vrouwezand was a few km from the coast, due to restrictions to sail closer to the shore. This location could be too far away from the coast to observe spawning. Location Flevocentrale was comparable to Houtribdijk with hard substrate. Fyke nets were placed close to the shore; only transparency levels were far too high. However, transparency could have changed just before the placement of the fyke nets, changing to clearer water, and making the water less suitable for smelt.

Based on the data gathered with examining ruffe stomachs, together with the results obtained from Houtribdijk, where smelt spawning was observed, the first tentative conclusion is that egg predation in Lake IJsselmeer and Lake Markermeer by ruffe is low. However, the comments mentioned before make this inventory inconclusive.


1
Approx. 1mm
2
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3
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5
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6
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8
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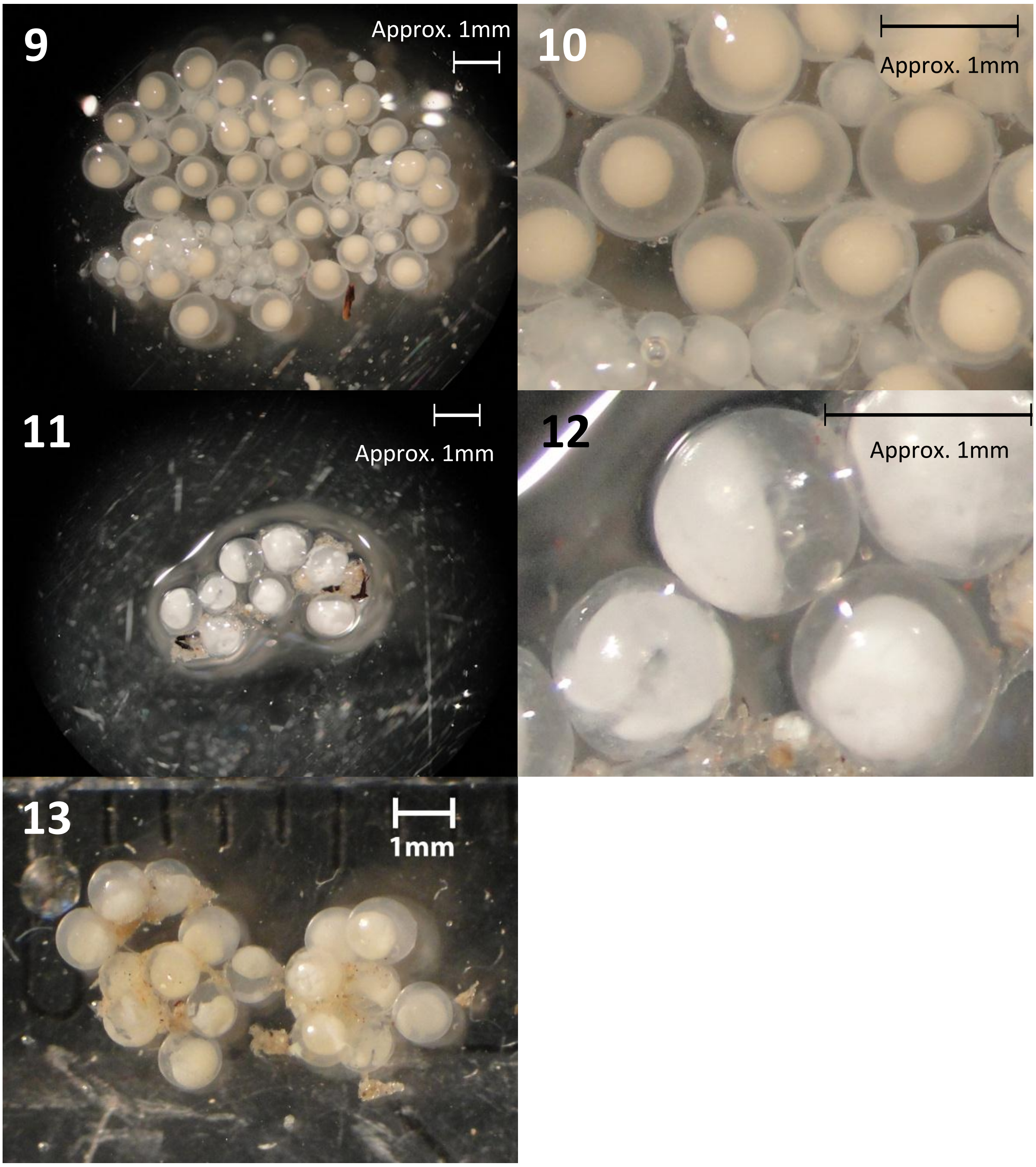

Figure 35. 1) Left smelt eggs, right contents from stomach; 2) Left contents out of stomach, right smelt eggs; 3) Left contents out of stomach, right smelt eggs; 4) Egg-shapes inside in the dissected stomach; 5) Ruffe eggs from female's gonads; 6) Egg-shapes in Gammarid with measured length; 7) Male ruffe with egg-shapes outside stomach; 8) Detail of 6; 9)Ruffe eggs; 10) Detail of ruffe eggs; 11) Fixed smelt eggs which were deposited on the nets; 12) Detail of smelt eggs; 13) Smelt eggs with measured length (same as 11, but different light source)

4. Conclusion and recommendations

Breeding success of common tern was in 2010 and 2011 poor to sustain a healthy population. As this situation continues, population size will further decrease, failing to reach objectives set by Natura2000. This study tries to give more insight in the common tern and his behaviour in relation to smelt and transparency levels in Lake IJsselmeer and Lake Markermeer.

Smelt stock differed from each other in 2010 and 2011 in terms of smelt stock in the lakes. The smelt stock in Lake IJsselmeer was higher in 2010 compared to 2011 while the opposite occurred in Lake Markermeer. Spawning of smelt occurred in 2011 one month earlier in contrast to 2010 for both lakes. This had no effect on the amount of smelt in the diet of the common tern. Smelt was the most important food source in July 2010 and 2011. Later in the season the proportion of other fish became more important

For the smelt, the 1+ year class had the highest proportion in weight. Even in low numbers, 1+ smelt accounted for most of the smelt biomass found in the diet of the common tern, especially in July for both years. Food with high energy in close proximity to the nest is needed for the common tern to fulfil their energy demands for themselves and the (almost full-grown) fledglings. However, while the diet of the adult birds showed no difference in the fish weight consumed compared to other months, breeding success was still poor for both years.

Later in the season proportion of the other fish species increased. Proportion of 0+ smelt also increased, but 1+ smelt remains important even in low numbers because of the high weight/energy compared to the 0+ smelt.

Transparency in Lake IJsselmeer was slightly higher in in July 2011 compared to 2010. These values were still in the cormorants intermediate transparency range (40-100 cm), but did not seem to affect the common tern. The species caught less fish in 2011, but weight per fish was higher, resulting in the same average weight per pellet compared to 2010. However, this could have been achieved by foraging in the more distant and turbid Lake Markermeer, as was seen in July 2011. It seems probable that the transparency was too high in Lake IJsselmeer and that conditions in Lake Markermeer were more suitable for the common tern to go to this more distant lake.

Transparency was (especially in Lake IJsselmeer) in 2011 higher in the first part of the common tern season. Also, proportion of smelt in the diet of the common tern was lower in 2011 compared to 2010. This could indicate that transparency may influence the smelt stock or the availability for the common tern later in the season. The transparency levels could also influence the behaviour of the common tern, instead of hunting on their own, association with cormorant groups could be sought. What this bond means for the food provision of the common tern has yet to be investigated.

As the common tern has a different hunting method than the cormorant, it was expected that the transparency range is smaller and closer to the lower values, as smelt tends to dive deeper with increasing clarity of the water. This seemed to be true in July when cormorant only caught 1+ smelt and in the common tern diet also 0+ smelt was found. It was also expected that common tern hunted during sunrise and sunset, as smelt tends to distribute more evenly in the water column. However, this behaviour was not seen in both days. But data still has to be compared if smelt still shows this behaviour.

This study shows a different proportion and length of 0+ and 1+ smelt is found in the diet of the common tern and the cormorant and the boat hauls.

By gathering pellets of common tern and cormorant at the same date, more comparisons could be made in the differences of the diet of both birds and, as the cormorant can dive, the distribution of the fish in the water column. Collecting pellets should happen especially after the 24-hour measurement (3x in the common tern season); both datasets could be compared to examine if the fish found in the diet could be attributed to the distribution of fish at the moment the birds hunted. However, a more reliable method would be to watch the common terns returning to the island with prey. This method, also conducted during this study by members of Bureau Waardenburg, has as advantage that only birds are counted that were actually foraging without the error of counting birds that do not show foraging behaviour. This can also be compared to the fish-distribution but mostly is to study the reasons while breeding success is poor, while the adult common terns seem to collect enough food for themselves. The increase of ruffe in Lake IJsselmeer did not help with the breeding success. As a benthic species that is rather bulky and spiny as well, it is not a good alternative for small plunge-diving birds. Its increase could even be related to smelt decline in several ways. The predation pressure of ruffe on smelt eggs however, is not confirmed or rejected. The diet of ruffe mainly consists out of zoobenthos. Only in stomachs of a few individuals egg-like shapes were found. It is still unknown if ruffe actively predates on smelt eggs. It is possible that ruffe migrates to smelt spawning locations to predate on smelt eggs, but no info is available about this behaviour in Lake IJsselmeer or Lake Markermeer.

To study the predation of ruffe and avoid confusion with other egg-shaped features, it is advisable to find an expert in gut contents of fish. Another possibility is to capture ruffe, collect smelt eggs and feed them under lab conditions to the ruffe. Depending on the budget and size of the research, this could give two results: 1. to show if the ruffe of Lake IJsselmeer and Lake Markermeer are eating smelt eggs, when giving the choice out of different food and 2. The visual appearance of smelt eggs in the stomach of the ruffe, to avoid confusion with other egg-shaped features.

Other factors should also be considered and studied. As the common tern is affected both by decrease of smelt abundance and by increase of transparency, changes would influence the population of the bird as well. An example of change is the strong increase of filtering quagga mussels (*Dreissena rostriformis bugensis*), which may have further negative effects in the near future. As many common terns that formerly bred in the Wadden Sea colonies have moved to Lake IJsselmeer when De Kreupel was built, this would have effect on the productivity of the entire Dutch population of the common tern, rendering the Natura2000 national conservation status of the species as unfavourable on the basis of prolonged poor breeding success alone.

References

Becker P. H., Frank D. & S. Sudmann, 1993. Temporal and spatial pattern of Common Tern (Sterna hirundo) foraging in the Wadden Sea. Oecologia 93: 389–393

Cramp S. (ed.), 1985. The birds of the western Palearctic 4. Oxford university Press, Oxford.

Van Eerden MR & A. Bij de Vaate, 1984. Natuurwaarden van het IJsselmeergebied. Flevobericht 242. Rijksdienst voor de Ussel-meerpolders, Lelystad

van Eerden M.R., Piersma T. & R. Lindeboom, 1993. Competitive food exploitation of smelt Osmerus eperlanus by great crested grebes Podiceps cristatus and perch Perca fluviatilis at Lake IJsselmeer, The Netherlands. Oecologia 93, 463-474.

Goudswaard P.C., Wanink J.H., Witte F., Katunzi E.F.B., Berger M.R. & D.J. Postma, 2004. Diel vertical migration of major fish-species in Lake Victoria, East Africa. Hydrobiologia 513: 141-152. [75]

Graaf M. de & M. Keller, 2010, 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. Imares Wageningen. report number C151/10

De Jonge C., 2008. Quick scan ambities recreatie IJmeer en Lake Markermeer; Resultaten literatuurstudie en workshop, Eindrapport. Stichting Recreatie, Kennis- en Innovatiecentrum

Mous P.J., Densen W.L.T. van & M.A.M. Machiels, 2004. Vertical distribution patterns of zooplanktivorous fish in a shallow, eutrophic lake, mediated by water transparency, PhD Thesis, Fish Culture and Fisheries Group, Wageningen University, P.O.Box 338, 6700 AH Wageningen, The Netherlands, Ecology of Freshwater Fish 2004: 13: 61-69

Ogle D.H., 1998. A Synopsis of the Biology and Life History of Ruffe, Journal of Great Lakes Research 24:170-185

Pearson T. H., 1968. The Feeding Biology of Sea-Bird Species Breeding on the Farne Islands, Northumberland. Journal of Animal Ecology, 37: 521-552

Piersma T., Lindeboom R. & M.R. van Eerden, 1988. Foraging rhythm of great crested grebes podicepscristatus adjusted to diel variations in the vertical-distribution of their prey Osmerus eperlanus in a shallow eutrophic lake in the Netherlands. Oecologia 76: 481-486.

Rijn S.H.M. van & M.R. van Eerden, 2002. Aalscholvers in het IJsselmeergebied: concurrent of graadmeter? Vogels, vissen en visserij in duurzaam evenwicht, RIZA rapport 2001.058, ISBN 90-369-5416-9

Winden J. van der, Dirksen S. & M.J.M. Poot, 2009. Laag broedsucces visdieven op de Kreupel in 2009: Voedseltekort in de grootste kolonie van West-Europa. Bureau Waardenburg bv. Culemborg

Annexes

Annex 1 Regression formulas for otholiths

These formulas are used to measure the fish length and weight on basis of fish remains found in the pellets of common tern and cormorant.

FL	= to be calculated fish length
FW	= to be calculated fish weight
OT	= the measured otolith length
PT	= the measured pharyngeal teeth length
PB	= the measured pharyngeal bone plate length
ln	= logaritmus naturalis

All lengths are expressed in millimetres, all weights are in grams

Fish lengths:

Smelt:	FL = 3.38+31.59 * OL
Ruffe:	FL = -11.31 + 22.14 * OL
Perch:	FL = -14.73 + 31.11 * OL
Roach:	lnFL = 3.897 + 0.734 · lnPB
Roach:	FL = 19,194PT + 58,984
Pikeperch:	FL = -27.20 + 40.64 · OL

Fish weights

Smelt:	FW = 0,0042*FL(cm)^{3,2}	(van den Winden *et al.*, 2009)
Smelt:	lnFW = -10.903 + 2.702 · lnFL	
Ruffe:	lnFW = -12.911 + 3.335 · lnFL	
Perch:	lnFW = -12.906 + 3.273 · lnFL	
Roach:	lnFW = -13.431 + 3.396 · lnFL	
Pikeperch:	lnFW = -15.593 + 3.722 · lnFL	

Taken from: (van Rijn & van Eerden, 2002; pers. comm. van Rijn, 2011)

Annex 2 Statistical output of lengths of smelt between 2010 and 2011 in the boat hauls

Output Mann-Whitney U test for lengths of 0+ and 1+ smelt caught in the boat hauls in similar months of 2010 and 2011

Lake	Age	Month	Test Statistic	P-value	Remarks
Lake IJsselmeer	0+	June	24746160.000	0.000	
Lake IJsselmeer	0+	July	637501.500	0.000	
Lake IJsselmeer	0+	August	342020.000	0.000	
Lake IJsselmeer	1+	July	71.000	0.028	N(2011)=1
Lake IJsselmeer	1+	August	3104.000	0.000	
Lake Markermeer	0+	June	1648.000	0.001	N(2010)=4
Lake Markermeer	0+	July	3844704.000	0.000	
Lake Markermeer	0+	August	226.000	0.000	
Lake Markermeer	1+	May	339.000	0.000	
Lake Markermeer	1+	June	17534.000	0.000	

Annex 3 Statistical output of lengths of smelt found in the boat hauls and the pellets

Output Mann-Whitney U test for lengths of 0+ and 1+ smelt in the diet of the common tern, cormorant and caught in the boat hauls in the months of 2010 and 2011

Lake	Age	Date	Method	Test Statistic	P-value	x < x < x	Remarks
Lake IJsselmeer	0+	Jun-10	Boat, Corm	0.000	0.000	Boat<Corm	
Lake IJsselmeer	0+	Jul-10	CT, Boat	37073.000	0.000	Boat<Corm	
Lake IJsselmeer	0+	Jul-10	CT, Corm	50.500	0.000	CT<Corm	
Lake IJsselmeer	0+	Jul-10	Boat, Corm	1748.000	0.000	CT<Corm	
Lake IJsselmeer	0+	Aug-10	CT, Boat	309.492	0.000	CT<Boat	
Lake IJsselmeer	0+	Sep-10	Boat, Corm	50,939.000	0.000	CT>Corm	
Lake IJsselmeer	0+	May-11	Boat, Corm	120.000	0.000	Boat<Corm	
Lake IJsselmeer	0+	Jul-11	CT, Boat	403.000	0.000	CT<Boat	
Lake IJsselmeer	0+	Aug-11	CT, Boat	8.000	0.000	CT<Boat	
Lake IJsselmeer	1+	Jul-10	CT, Boat	964.000	0.000	Boat>Corm	
Lake IJsselmeer	1+	Jul-10	CT, Corm	90695.500	0.000	CT>Corm	
Lake IJsselmeer	1+	Jul-10	Boat, Corm	87683.000	0.000	CT<Boat	
Lake IJsselmeer	1+	Aug-10	CT, Boat	1358.000	0.000	CT<Boat	
Lake IJsselmeer	1+	Sep-10	CT, Corm	1302.500	0.000	CT>Corm	
Lake IJsselmeer	1+	Jul-11	CT, Boat	4095.000	0.022	CT<Boat	N(Boat)=1
Lake IJsselmeer	1+	Aug-11	CT, Boat	0.000	0.000	CT<Boat	
Lake Markermeer	0+	Jun-10	Boat, Corm	372.000	0.131	Boat=Corm	N(Boat)=4
Lake Markermeer	0+	May-11	Boat, Corm	225.00	0.000	Boat<Corm	
Lake Markermeer	0+	Jun-11	Boat, Corm	89360.000	0.000	Boat<Corm	
Lake Markermeer	0+	Jul-11	CT, Boat	15860.000	0.000	CT<Boat	
Lake Markermeer	1+	May-10	Boat, Corm	3284.000	0.000	Boat>Corm	
Lake Markermeer	1+	Jun-10	Boat, Corm	45468.000	0.000	Boat>Corm	
Lake Markermeer	1+	May-11	Boat, Corm	918.000	0.000	Boat>Corm	
Lake Markermeer	1+	Jun-11	Boat, Corm	50590.000	0.000	Boat>Corm	