ROLE OF THE THREE-SPINED STICKLEBACK GASTEROSTEUS ACULEATUS L. IN THE FOOD ECOLOGY OF THE SPOONBILL PLATALEA LEUCORODIA

by

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(With 9 Figures)

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Summary

In a five year study (1985-1989), the importance of the three-spined stickleback, *Gasterosteus aculeatus* to the spoonbill, *Platalea leucorodia* was elucidated. Both species migrate from distant areas to meet in polder areas as prey and predator, in the Netherlands. In the spring, spoonbills fly all the way from Africa and the south of Spain to breed in colonies. As long as juvenile spoonbills are not able to fly, the demand for food is high, and the supply from the foraging areas is of vital importance. The availability of food in the foraging areas around one of the major spoonbill colonies was studied. Different food situations (prey items, prey density) were judged by means of the average food intake rate. Food situations in which prey items weigh over 2 gram, turned out to be most favourable. Prey density was of less importance.

Anadromous three-spined sticklebacks migrate from the sea in the spring to breed in shallow ditches and back waters. Their body weight is about 2.5 gram which makes it an excellent prey for the spoonbill. Unfortunately, in the last decades, it has become very hard for the anadromous stickleback to migrate into polder areas. Modernisation of agriculture has led to a situation in which open connections between channels and polder area have disappeared. The presumed benefit of the anadromous stickleback for the spoonbill was tested, by transporting 1,000 kilogram of anadromous sticklebacks to a polder area. The impact on the spoonbills was studied in a two year period. Since there was a distinct effect on the spoonbill, it was decided to design a fish ladder to enable anadromous sticklebacks to enter the polder again. The concept was tested in 1988. In 1989 a permanent construction was built.

Introduction

The spoonbill, *Platalea leucorodia* is considered an endangered species in the Netherlands (OSIEGK, 1986, 1987). The species suffered from a sudden decrease in number around World War II. There exist several explanations for this. A vulnerable part in the life cycle is the migration. On the way between Mauritania, Senegal and the south of Spain to Holland, many spoonbills feil victim to hunters (POORTER, 1982). Other possibilities are pollution (ROOTH & JONKERS, 1972), deterioration of foraging areas and the disappearance of sanctuaries where the birds can breed (BROUWER, 1964).

Relatively little attention has been paid to the food ecology of the spoonbill (POORTER, 1979), while the food situation is essential for the spoonbill during the breeding season. Juvenile spoonbills stay in the colony for about seven weeks before they follow their parents to foraging areas. Until that time, at least 500 grams of food per day must be gathered by an adult to support its young and itself (KING, 1974). More food means the survival of more juveniles.

The study concentrated on the food ecology of the spoonbill and the role of the three-spined stickleback in it. The study period can be subdivided into three parts. In the spring of 1985, the study focused on the food ecology of the spoonbill of Het Zwanenwater (WOETS, 1972), a nature reserve in the dunes near Gallantsoog (Noord-Holland) with 61 breeding pair of spoonbills in 1985. The first spoonbills arrive in late February. From that time on spoonbills can be found in the foraging areas untill the end of June. By that time the last juveniles are able to accompany the adults to more remote foraging areas. Measurement of the food intake rate at different locations were used to reveal the most favourable circumstances with respect to food availability. From this study it became clear that the weight of the prey is the key for high food intake rates, rather than the density of the prey.

In the spring, anadromous sticklebacks migrate from the sea into inland waters to spawn. After the summer when food gets scarce, the young sticklebacks go to sea to return as adults in the next year. The lifespan for anadromous sticklebacks is little more than one year (BAGGERMAN, 1957). Migration is believed to be a mechanism to explore the best foraging areas in the course of the seasons. This may account for the difference in average weight between fish from anadromous and resident freshwater populations (MÜNZING, 1963; VAN MULLEM & VAN DER VLUGT, 1964; WOOTTON, 1976). The average weight of the seagoing specimens is 2.5 gram. This fits in very well with the food preference of the spoonbill. In contrast, resident three-spined and ten-spined sticklebacks weigh on average only 0.7 gram. However, in the past decades migration is inhibited by the modernisation of agriculture. Since the weight of the prey is of such great importance for the food intake rate, special attention was paid to the anadromous three-spined stickleback.

The second part of the study was carried out in the spring of 1986/87. The principal aim was to find evidence for the alleged importance of anadromous sticklebacks to the spoonbill. For this experiment a polder was artificially enriched with anadromous sticklebacks. From the presence of foraging spoonbills, the impact was measured.

Encouraged by the results in the previous years, a fish ladder for sticklebacks was designed, tested and built in 1988/89.

Materials and methods

Study area.

The study on the food intake rate, took place in different foraging areas of the spoonbill in the Netherlands. The areas are roughly indicated by the circles in Fig. 1. The spoonbill colony is situated in the Zwanenwater, a sanctuary in the dunes near Callantsoog. The specific experiment on the relationship between anadromous sticklebacks and the spoonbill was carried out in the polder Wieringerwaard. At the pumping engine of the same polder the fish ladder was built and tested.

Food intake rate of the spoonbill.

Food intake rate can be computed according to the following equation.

$$F = (W \times G) \times S$$

F: Food intake rate ($kjoule.minute^{-1}$)
W: Average weight of the prey population (gram)
G: Calorific value ($kjoule.gram^{-1}$)
S: Swallow frequency (prey items per minute search time)

According to the type of prey, the foraging range of the spoonbill can be divided into four areas (Fig. 1).

1. The largest area covers the polders around the town of Schagen. In the polder ditches sticklebacks are practically the only fish encountered. Two species can be distinguished: the three-spined stickleback and the ten-spined stickleback.
2. The brackish water area behind the Hondsbossche Zeewering. In this area the three-spined stickleback is not uncommon but is outnumbered by a prawn.
3. The Balgzand, a tidal mudflat, becomes an important foraging area at about the beginning of June. In this area the spoonbill eats mainly the common shrimp (TINBERGEN, 1934; WETTEN & WINTERMANS, 1986).
4. The fourth area is near Hoorn where small rudd and bream are on the spoonbill's menu.

Since these species occur in separate areas, there was little or no confusion about the exact species the spoonbill ate at a certain spot. The average weight of prey eaten was derived from the average weight of the resident prey population. For this purpose prey was caught with a sampling net (Fig. 2) after each behavioural protocol at the spots where spoonbills foraged. Samples were taken by putting the net vertically into the water and then quickly moving it towards the sampler. This was repeated until at least 20 and at most 100 prey items were caught. After sampling no additional protocols were made at the same spot within several hours.

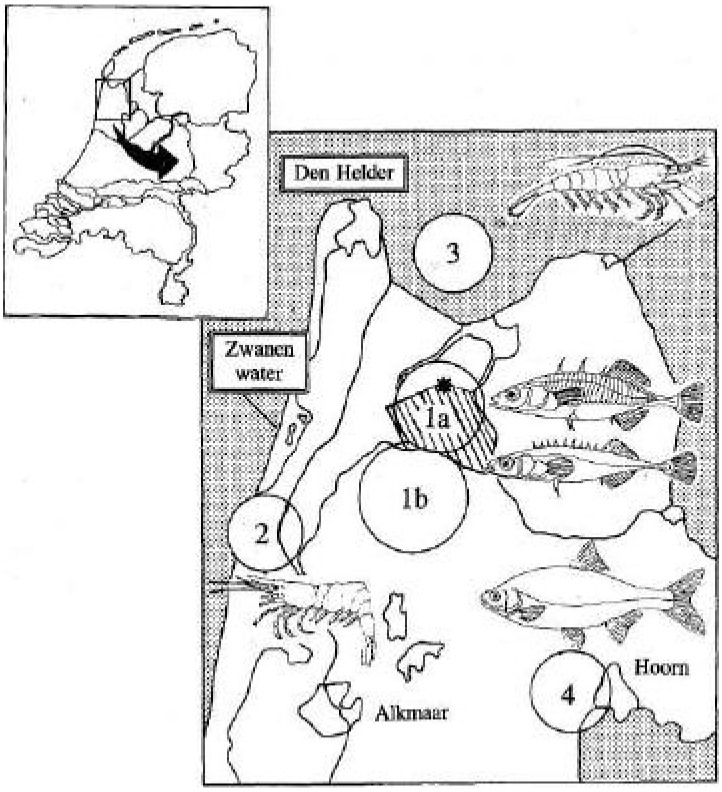

Fig. 1. Map of the various study areas in the province of 'Noord-Holland', The Netherlands. The spoonbill colony is situated in the 'Zwanenwater'. Indicated are the major foraging areas of the spoonbill and the predominant prey types in each area. la, b: freshwater three-spined stickleback, *Gasterosteus aculeatus* and ten-spined stickleback, *Pungitius pungitius;* 2: prawn, *Palaemonetes varians;* 3: common shrimp, *Crangon crangon;* 4: rudd, *Scardinius erythropthalmus,* and bream, *Abramis brama.* The polder 'Wieringerwaard' in which the feeding experiment took place is shaded. The location of the siphon fish ladder is marked by an asterisk.

In addition to the average prey weight, calorific values (kjoule.gram^{-1}) were determined, because there is some difference in energetic contents between different prey items. Samples were weighed (fresh weight) and dried in a desiccator (dry weight). The dried prey was homogenized in a mortar. For the actual measurement of the calorific value a 'Phillipson Microbomb Calorimeter' was used.

Spoonbills search for food by sweeping the slightly opened bill through the water. When a prey is caught, the bird lifts up its head to swallow the item. This swallowing movement can be clearly distinguished from all other foraging behaviour. The swallow frequency was expressed as: swallowed prey items per unit of time the birds were searching for food (sweeping). Interruptions, like looking around for danger, were excluded. Foraging spoonbills were located while driving around by car in the study area. Since birds are easy to disturb most behavioural protocols were made from the car. Birds were observed with a 60

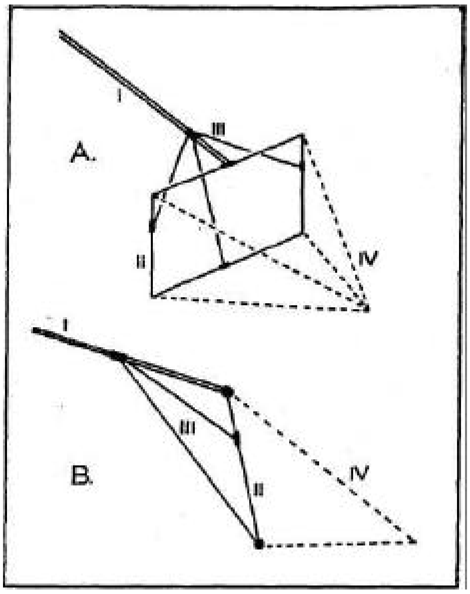

Fig. 2. Sampling net. The net was used to determine the type and average weight of prey eaten by the spoonbills. Sampling took place at the spots where foraging spoonbills were observed. A: 3- dimensional view of the net. B: Side view. I: Handling stick. II: Window frame (80 x 40 cm). III: Support rods. IV: net (5 mm mesh).

mm telescope with a magnification in the range of 15 to 60. Behavioural protocols could be made up to a distance of 400 meter under cold and clear weather conditions. The spoonbills were observed as long as possible till they departed. The length of the behavioural protocols varied between 5 and 32 minutes. For the recording a portable tape recorder was used.

Reintroduction of anadromous sticklebacks in the foraging area of the spoonbill.

The effect of the reintroduction of anadromous sticklebacks on the number of foraging spoonbills, was studied in the polder Wieringerwaard. The area (4x5 km) is located 10 km northeast from the colony. The polder is divided in two equally sized areas, hydrologically separated from each other (Fig. 1), and are referred to as the experimental and control area. In the first year of the experiment (1986), no sticklebacks were released. In 1987, approx. 1000 kilo of anadromous sticklebacks were released in the experimental area.

The anadromous sticklebacks had been collected by a fisherman in Den Helder. Transportation to the study area took place at night on a little trailer (1 x 2 m). Sticklebacks were put on the trailer on a wet blanket in a layer of approx. 10 cm thick (Fig. 3). In 20 minutes the fish were released in the experimental area within the polder Wieringerwaard. All fish survived this method of transportation, which started on the 14th of April 1987 and lasted for two weeks. The fish were released at different points in the area to promote distribution.

The effect of the introduction of sticklebacks on the spoonbill was measured by comparing the numbers of foraging spoonbills in the two areas both before and after release of

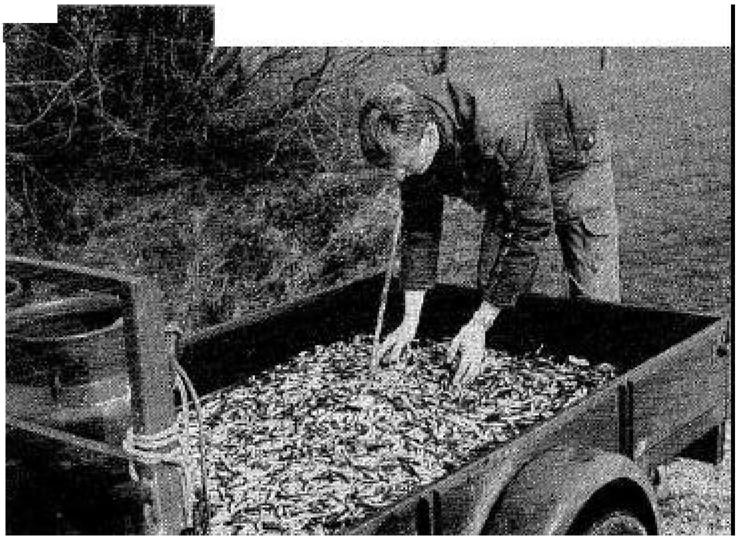

Fig. 3. Transport of sticklebacks in a 10 cm layer of fish. The survival rate after a 20 minutes transport from the sea to the polder, was 100%.

sticklebacks. For the spoonbill census a fixed route was followed by car every two or three days. About 65% of all ditches were observed.

Fish ladder for sticklebacks (The siphon fish ladder).

Although there is much literature on fish ladders, most designs concentrate on upstream migration. Three-spined sticklebacks are anadromous, so their movement in the spring is upstream too. However, in the Netherlands there are special circumstances that make the appliance of existing designs impossible. The problem is that polder areas drain their surplus water into a channel that has a higher level than the polder. Consequently, anadromous sticklebacks moving upstream against the current will congregate at the outlets of the pumping engines of the polders, unable to enter the original breeding grounds and out of reach for the spoonbill. The problem was solved by forcing the fish into the polder by a siphon (The siphon fish ladder).

The siphon fish ladder is based on the collection of sticklebacks into a compartment by an attraction flow, after which they are automatically siphoned into the polder. The efficiency of the attraction flow was tested in 1988 by submerging a compartment of 2 x 2 x 2 meter near the pumping engine of the Wieringerwaard. An attraction flow was led through it. The compartment was daily checked for sticklebacks which were subsequently released into the polder.

Results

Prey profitability for the spoonbill.

Equally distributed over the different foraging areas, 84 recordings of the foraging behaviour were made. These observations were made on the 122

(61 pairs) spoonbills that inhabited the Zwanenwater colony that year. Since only a few spoonbills were marked, it was unclear how many times the same bird was observed.

The recordings were classified according to the average wet weight of the prey at the exact spot where the foraging took place. This resulted in five weight classes. The weight classes of 0.1, 0.2, 0.4, 0.7 and 2.0 g were dominated by juvenile stickleback, juvenile shrimp, shrimps and prawn, adult stickleback, and rudd and bream, respectively.

According to expectation, the swallow frequency of foraging spoonbills decreased with increasing size of the prey items (Fig. 4); Spearman rank correlation coefficient $r_s = -1$, $N = 5$, $p = 0.02$. Based on the swallow frequency, the average weight of the prey, and the calorific value (Table 1) of the dominant prey, food intake rates were calculated for the various weight classes of prey. Foraging in areas with relatively large prey resulted in significantly higher food intake rates (Fig. 5). The statistical significance of the differences were tested with Kruskal-Wallis ANOVA (Siegel & Castellan, 1988). The KW-value of 78.7 indicated that at least one of the classes differs significantly from at least one of the other classes ($p < 0.001$). Subsequently a multiple comparison between classes was conducted to test the mutual differences between the five weight classes. The difference between seven out of ten of these comparisons

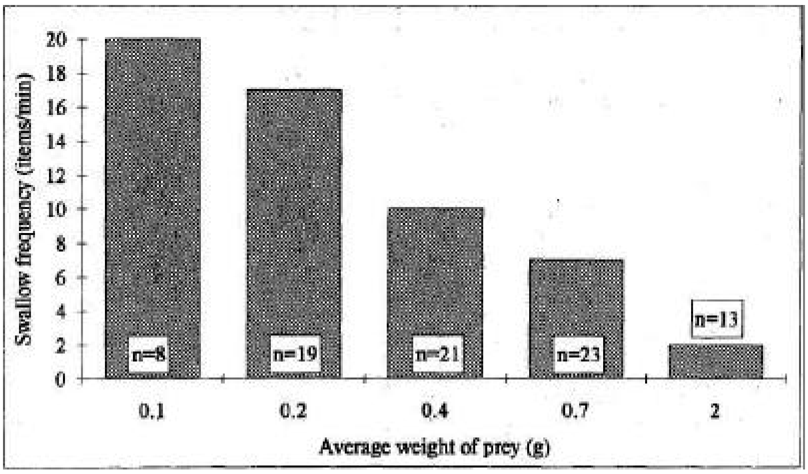

Fig. 4. Average swallow frequency (items.min^{-1}) of foraging spoonbills for different weight classes of prey (g). The number of observations for each weight class are indicated.

TABLE 1. Calorific values (in kjoule.g^{-1}) of different species of prey with 95% confidence limits (CL) of the mean

Species	kJoule.g^{-1}	N	CL
P. pungitius	*4.86*	*12*	*0.14*
G. aculeatus	*4.50*	*18*	*0.08*
P. varians	*3.70*	*11*	*0.07*
C. crangon	*3.70*	*12*	*0.06*
S. erythropthalmus & A. brama	*4.50*	*6*	*0.06*

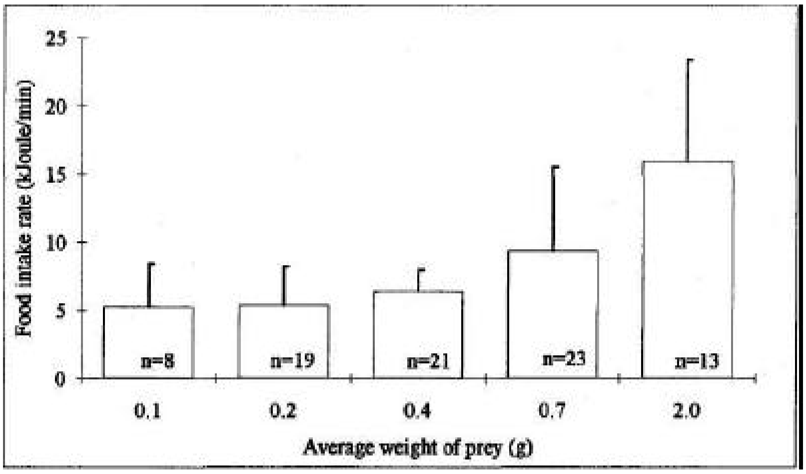

Fig. 5. Correlation between the average (+ 1 SD) food intake rate (kjoule.min^{-1}) of foraging spoonbills and the average weight of prey (g). The number of observations in each weight class are indicated.

were significant ($p < 0.05$; two-tailed). No significant difference could be indicated between the following classes: 0.1-0.2 g, 0.2-0.4 g, and 0.7-2.0 g

Impact of anadromous sticklebacks on the spoonbill.

In standardized census during March, April and May 1986, 56 foraging spoonbills were spotted during 28 visits to the experimental and control area in the Wieringerwaard polder. In the same months of the next year, the year of the introduction of anadromous sticklebacks in the experimental area, 164 birds were spotted during 34 visits to the same areas. The total number of birds spotted on each census in the experimental and control area together, is given in Fig. 6.

The spring of 1987 was extremely cold, so spoonbills arrived three weeks later in 'Het Zwanenwater' than in 1986. But also the stickleback immigration from the sea at Den Helder was delayed for many weeks. High concentrations were not observed before the first week of April.

In 1986, the number of foraging spoonbills in the experimental area and in the adjacent control area were similar (Table 2). In the year of stickleback release significantly more spoonbills foraged in the experimental area than in the control area (Table 2), due to an increase of foraging birds in the experimental area in the month following stickleback release (Fig. 6).

Beside the spoonbill census, samples were taken from the stickleback population after the release. From these samples, the effect of the release on stic kleback density was calculated. The mean weight of the anadromous sticklebacks before release was 2.5 gram (SD = 0.52, N = 1020). The resident freshwater sticklebacks weighed on average 0.57 g (SD = 0.18, N = 445). The populations overlap in a small range (Fig. 7a). After the release of the anadromous fish in the freshwater population, the

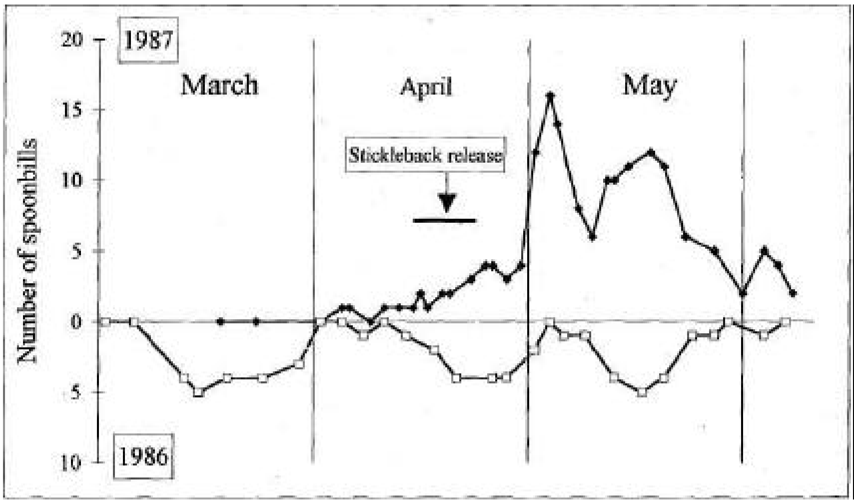

Fig. 6. Results from the standardized spoonbill census during March, April and May of 1986 and 1987. The sum of foraging spoonbills in the experimental and control area is given. During the second half of April 1987 1000 kg of anadromous sticklebacks were released in the experimental area.

TABLE 2. Number of foraging spoonbills in two equally sized areas in the Wieringerwaard polder counted on standardized census trips during 1986 and 1987

Area	Number of foraging spoonbills in 1986	1987
Experimental	31	134
Control	25	30
	$X^2 = 14.09$, df = 1, $p < 0.0001$	

Sticklebacks were introduced in the experimental area in 1987.

weight frequency distribution of the mixed population was determined. This distribution was based on all stickleback samples used for the determination of the food intake rate of the spoonbill, and supplemented with additional catches up to 1341 sticklebacks (Fig. 7b). From this distribution it is clear that the population density increased less than 5% due to the release.

The siphon fish ladder.

The concentration of sticklebacks by means of an attraction flow worked out well: in the spring of 1988, approx. 40 kg of sticklebacks could be removed from the container, daily. In total 780 kg was moved from the container to the polder (Fig. 8). In addition to sticklebacks, about 10 kg small eel, *Anguilla anguilla,* adult carp, *Cyprinus carpio,* small rudd and perch, *Perca fluviatilus* were gathered. In 1989 the siphon was tested and fish were verified at the end of the siphon. No visible damage could be noticed. Figure 9 gives a schematic drawing of the so called 'Siphon fish ladder' that takes care of the transportation of the fish into the polder.

Two parts can be distinguished. The first part takes care of the concentration of sticklebacks in a restricted compartment (stickleback compartment). To get the fish inside this compartment, polder water is pumped through the compartment and through the stickleback entrance hole into the channel (attraction flow). Both the current from the entrance hole and the chemical components *(e.g.* humic acids) of the polder water lure the fish inside.

The second part takes care of the transportation of the fish to the polder by means of a siphon. To get a water flow through the siphon, a

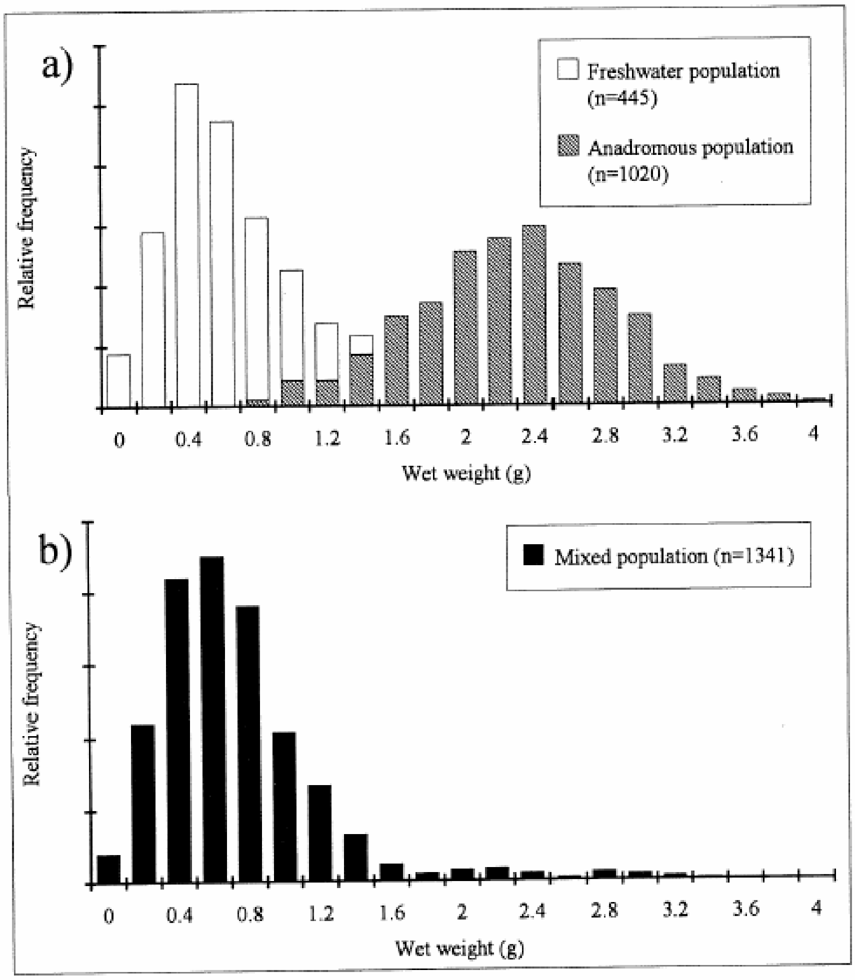

Fig. 7. Frequency distributions of the wet weight of anadromous sticklebacks (shaded bars) and freshwater sticklebacks (blank bars) a) before release of the anadromous fish in the freshwater pop u-lation, and b) after release. Fish that were heavier than 1.4 gram were assigned to introduced ana-dromous fish

vacuum pump sucks the air from the siphon tube. When the water level in the compartment drops, a valve at the entrance hole will close, blocking further entry, and all the fish and water in the compartment will be siphoned to the polder. When the compartment is emptied, air will enter the tube and the si-phon stops. The compartment fills up again, the valve

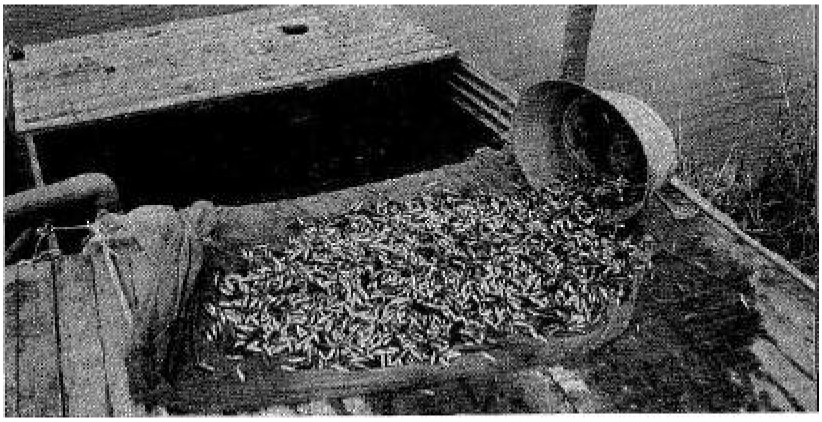

Fig. 8. The 12 kilogram of sticklebacks on the photograph were gathered within a few hours in the afternoon in a large container by means of an attraction flow (experimental stage of stickleback ladder).

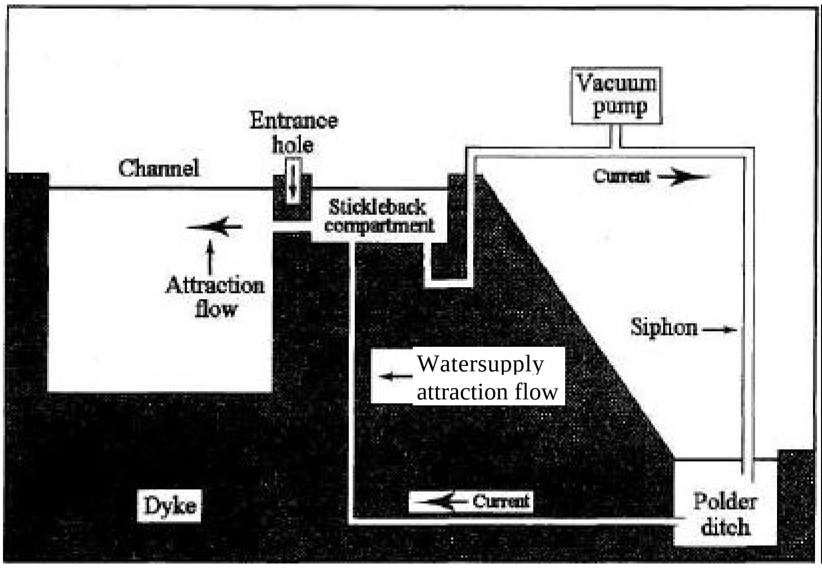

Fig. 9. Outline of the siphon fish ladder. The dyke is a barrier that separates the channel from the polder ditch, and so disables anadromous sticklebacks to migrate to spawning grounds. The siphon fish ladder is designed for this typical Dutch problem. For an explanation see the text.

opens and new fish can enter for a next round. The vacuum pump is controlled by a timer that delivers a pulse every hour.

Discussion

There existed a clear relationship between the average weight of the prey and the swallow frequency of foraging spoonbills. This is not surprising since smaller prey will be, on average, more abundant than bigger prey. In addition, bigger prey is swifter and therefore harder to catch for the spoonbill. Also may handling time be longer for larger prey items. Much harder to predict, is the relationship between the average weight of prey and the food intake rate. Simply because it is unclear which combinations of prey size and prey density are present in the foraging areas, and because prey items differ in calorific values. It can be imagined that both small preys in high densities and large prey in moderate densities, result in high food intake rates. This study showed that the highest food intake rates were obtained in foraging areas with large prey items.

Spoonbills are generally associated with small prey items like aquatic insects, their larvae, molluscs, worms, leeches and fish (Gramp & Simmons, 1977). The most favourable items are nevertheless much bigger as the results of my study show. This misconception is easily explained by the fact that foraging areas with large prey and moderate densities are rare. Spoonbills will therefore be seen most in inferior food situations, suggesting that these are the most favourable ones.

Because the Netherlands are in fact a large delta area, they have been subject to many hydrodynamic changes. In the beginning of the century there were still possibilities for anadromous fish to migrate from sea into shallow ditches and back waters. The annually recurring invasion of sticklebacks did not only contribute quantitatively to the food supply of the spoonbill. The greatest advantage lay in the average weight of the prey: approx. 2.5 gram for anadromous sticklebacks as compared to 0.7 gram for the freshwater sticklebacks with which the spoonbills have to deal now. Since no locations were known where anadromous sticklebacks can enter the foraging areas of the spoonbill, this situation was artificially created in order to study the effect on the spoonbills.

Reintroduction of (large) anadromous sticklebacks in the polder caused an increase of foraging spoonbills compared to the number of foraging spoonbills in an adjacent, unmanipulated control area where the birds fed on (small) freshwater sticklebacks. The improved food situation resulted in an increase in flock-size. Flocks of twelve birds were no exception, while five birds in one group is the maximum ever observed during the breeding season in previous years. For the blue heron, KREBS (1973) pointed out that flocks occur at places where feeding conditions are good, rather than that foraging in flocks favour high food intake. The increase in the density of the sticklebacks in the experimental area due to the release of the sticklebacks was small. Therefore, it is most likely that spoonbills were attracted to the area by the quality (size) rather than by the slight increase in prey density.

The positive effect of anadromous sticklebacks on the foraging efficiency of spoonbills led to the development and building of a permanent stickleback ladder. The siphon fish ladder transports large quantities of anadromous sticklebacks to the polder in the spring. The siphon fish ladder can only be applied at locations near pumping engines. The little attraction flow through the compartment is too weak to be sensed by sticklebacks at great distances. The pumping engine which pumps surplus water from the polder into the channel causes a much stronger water flow that attracts the immigrating sticklebacks. In dry periods when the pumping engine does not work the supply of sticklebacks is low. This is however seldom the case in the spring.

It was expected that the effect of the fish ladder could be assesses from an increase in breeding spoonbills. Unfortunately this was not possible. In the same year when the siphon fish ladder was built, the spoonbill colony was disturbed by foxes. All juveniles were killed and the adults were driven to other colonies. In the past five years, the breeding population in the Zwanenwater increased again. But it would be very hard to relate this to the measures taken in the polder Wieringerwaard.

In 1995, a second siphon fish ladder will be built on the island of Texel. This ladder establishes a direct link between the sea and the polders of the Island and must provide food for the three spoonbill colonies there.

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