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DISTRIBUTION OF THE FOOD SURPLUS AND FAECAL PARTICLES ON THE SEABED BELOW A FISH FARM IN THE BAY OF PIRAN

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ABSTRACT

Simulations of the spread of food pellets and faecal particles beneath a fish farm were performed on the basis of field measurements of currents and laboratory measurements of settlement velocities. The simulations showed that the patch of the food surplus at the sea floor covered an area smaller than 30 x 15 m, while faecal pellets should have covered an area smaller than 300 x 150 m.

Key words: mariculture, currents, environment, Bay of Piran

DISTRIBUZIONE DI ECCESSO DI MANGIME E PARTICELLE FECALI SUL FONDO MARINO SOTTOSTANTE UN ALLEVAMENTO DI PESCI (BAIA DI PIRANO)

SINTESI

L'articolo riporta simulazioni della dispersione di pallottoline di mangime e particelle fecali al di sotto di un allevamento di pesci, ottenute da misurazioni di correnti sul campo e misurazioni in laboratorio delle velocità di affondamento del materiale organico. È stato dimostrato che l'eccesso di mangime va a ricoprire un'area minore di 30 x 15 m, mentre le particelle fecali restano confinate in un'area di 300 x 150 m.

Parole chiave: maricoltura, correnti, ambiente, Baia di Pirano

INTRODUCTION

Fish farming, in comparison to fishing of the wild stocks, has economic advantages, but it also presents a threat to the ecological equilibrium in the marine environment. Different influences are coming from the mariculture in a form of the food supply surplus, solid and dissolved excrements, and as a wide range of different pharmaceutical drugs. There are two types of particles that enter the ecosystem from the fish farm: the fish food surplus, that is the part of the food supply that is not consumed by fish and passes through the nets of the cage, and fish excrements. This process increases the consumption of dissolved oxygen (short-term impact) and the accumulation of decayed material in the upper layer of the sediment. The latter process is considered as a long-term impact since this material at the surface film of the seabed is later regenerated. This means that proper planning of the fish farm location should consider the amount of particles deriving from the farm and their spreading around the cages. The paper presents the simulation of the distribution of food surplus particles and faecal pellets on the seabed due to the horizontal advection of the water mass during their sinking below the fish farm.

MATERIALS AND METHODS

The shallow Bay of Piran (Fig. 1) is part of the northern Adriatic Sea and is opened to the Gulf of Trieste. The depth beneath the cages is 13 ± 1 m; depth variations are caused mainly by tides. The sea floor is smooth and muddy, with a moderate declination towards the open sea. The water column structure resembles that of the Gulf of Trieste (Malačič, 1991) with seasonal temperature variations. However, at the fish farm site the influence of the river Dragonja modifies the vertical stratification in the shallow water column, in particular the distribution of salinity. Records of monthly data collected at the two nearby stations that are less than 1.5 km away (Tab. 1) show that during the spring-summer time (Forte, 2001) temperature in the upper part of the water column varies between 18-26 °C, and between 12-17 °C in its lower part. Salinity also shows some seasonal variations, although less pronounced, for it varies between 28.0 – 38.5 PSU in the upper part of the water column.

Currents were measured on the fish farm site (45°29.226′ N, 13°34.838′ E) with the acoustic Doppler current-meter profiler of Nortek AD company (NDP) mounted on the sea floor. The instrument scans the water column above with three beams and outputs the velocity of layers that are 1 m thick. The average period of currents was 600 s, while the sampling period was 3600 s. Measurements were performed in the spring-summer period, from 19 April to 4 July and from 31 July to 31 August 2000.

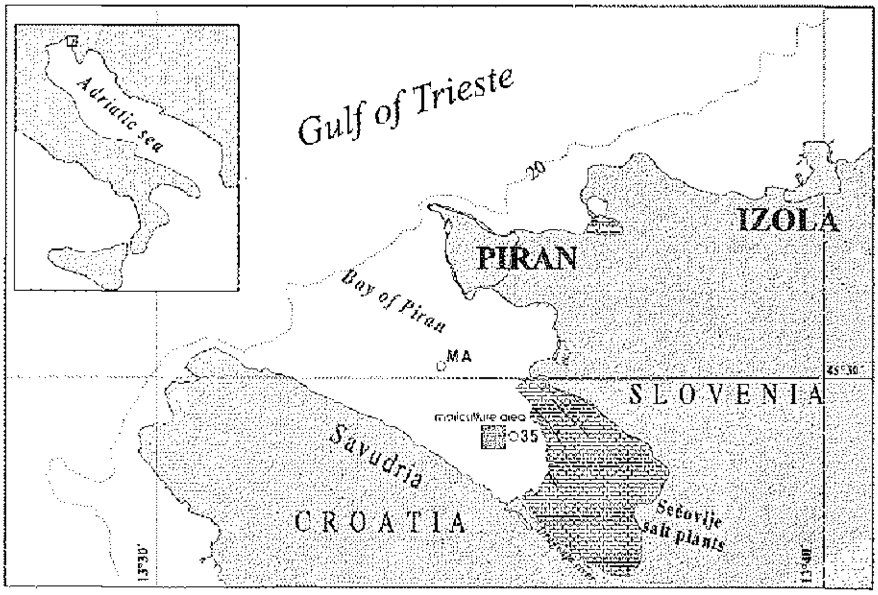

Fig. 1: Location map of the fish farm and the nearby measurement stations MA (45°30.20′ N, 13°34.20′ E, depth 16 m) and 35 (45°29.40′ N, 13°35.00′ E, depth 12 m) from where the long-term temperature and salinity records were applied for the estimate of density on the farm site.

Sl. 1: Skica lokacije ribogojnice in bližnjih merilnih postaj MA (45°30.20′ N, 13°34.20′ E, 16 m) in 35 (45°29.40′ N, 13°35.00′ E, 12 m), kjer so bile opravljene dolgoročne meritve temperatur in slanosti za kasnejši izračun gostote morske vode.

Tab. 1: Simple statistics of 1362 temperature and salinity data obtained in 25 years in the Bay of Piran (1975-2000). The average value is denoted with < >, and deviation with SD. Sampling was performed at stations 35 and MA and at four different depths: on the surface, at depths ranging from 5 to 10 m, and just above the sea floor (Ruttner sampling).
Tab. 1: Osnovni statistični podatki o temperaturah in slanostih, izračunani iz 1362 meritev, pridobljenih v 25 letih (v obdobju 1975-2000) v Piranskem zalivu. Znak < > označuje srednjo vrednost, SD pa standardno deviacijo. Meritve so bile napravljene na postajah 35 in MA na štirih globinah (površina, 5 m, 10 m in tik nad dnom – Ruttnerjev vzorčevalnik).

	T (ş C)	S (PSU)	σ_T (kg/m^3)
< >	15.67	36.88	27.16
SD	5.42	1.02	1.73
Min	5.85	28.77	20.69
Max	27.63	39.83	30.89

Sinking velocity of fish food and fish excrements was measured in the lab. Measurements of the sinking velocity of fish food were performed in a plastic cylinder filled with seawater with salinity of 37.5 PSU and temperature of 22.5 °C. This seawater density is thereafter calculated as 25.9 kg/m^3. From twelve throws of fish pellets, the highest and the lowest measured velocity were eliminated; from the remaining ten values the average and the standard deviation (SD) were calculated. We combined the sinking velocity of fish food with the current-meter data to predict the distribution of unconsumed fish food on the seabed below fish cages.

This idea of simulating the distribution of unconsumed fish food was extended to faecal particles. For this reason, faeces were collected from the fish cage using a particular trap of polyethylene foil. The foil covered an area of 1 m^2 at the bottom of the cage, with a plastic bottle attached in its centre as a recipient of the sinking material. In the laboratory, a sample of collected particles with a volume of 1.5 l was diluted to 5 l and carefully mixed to achieve more homogeneous distribution of excrement. From this mixture, a sub sample of 5 ml was taken and released into another plastic cylinder, in which the sinking velocity was measured. This second cylinder was filled with seawater collected a few miles away, with temperature of 22.0 °C, salinity of 38.5 PSU, and the calculated density of 26.9 kg/m^3.

RESULTS AND DISCUSSION

In the year 2000, currents at the fish farm were measured twice, in the late spring (19 April – 5 July) and summer (31 July – 31 August 2000) periods. Frequencies of the directions of currents show (Forte, 2001) that in late spring the prevailing currents over the whole water column were directed towards NE and E (30% – 40%), while they were more evenly distributed during the summer, with more frequent directions towards NW, W and SW (15% – 20%). In both cases, the frequency of directions towards the south was not higher than 10%, indicating that over the entire water column the currents were mostly oriented away from the mouth of the Dragonja river (Fig. 1) during the spring-summer period. The distribution of velocity magnitude in different directions (eight sectors) show higher values of currents in NE and E directions during late spring, while during the summer period currents had evenly distributed magnitude in all directions.

Currents in the surface layer 11 m above the NDP and about 2 m below the sea-surface deviated from the rest of the water column during the spring period. The most frequent directions then were to the E or W, and their velocities reached values of 0.17 m/s in the W direction and of 0.15 m/s in the E direction. During the summer period, however, surface currents had similar directions as the rest of the water column. This indicates that the surface layer is dominantly wind-driven, since during the spring period the wind is more frequent than during the summer (Ogrin, 1995), while in the rest of the water column tidal and density driven currents prevail.

Tab. 2: Sinking velocities (mean±SD) of fish food pellets and faecal particles, measured in the lab. Seawater density for the experiment with pellets was 25.9 kg/m^3 and density for the experiment with faecal particles 26.9 kg/m^3.
Tab. 2: Hitrosti padajočih delcev ribje hrane in delcev ribjih iztrebkov (srednja vrednost±SD). Meritve so bile opravljene v laboratoriju. Gostota morske vode med poizkusom z ribjo hrano je bila 25,9 kg/m^3, medtem ko je bila gostota med poizkusom z delci iztrebkov 26,9 kg/m^3.

	Sinking velocity (cm/s)	
	Pellets	**Faeces**
< >	5.72	0.64
SD	0.15	0.05

Sinking velocities of food pellets were estimated in the lab as 5.7 ± 0.15 cm/s (Tab. 2). In comparison to food pellets, the sinking of faecal particles was significantly slower. Their sinking velocity was estimated at 0.64 ± 0.05 cm/s, being roughly 8.9 times smaller than that of food pellets. This means that through the water column of the same density as the one of the seawater in lab cylinder, food pellets would pass vertically through a layer of thickness of 1 m in less than 18 s, and would reach the sea floor from the surface in less than 3.8 minutes. Faecal particles would travel through a layer of 1 m on average in less than 157 s, and would reach the sea floor in less than 34 minutes. Since currents were measured with a sampling rate of 1 hour, we reasonably assumed that both types of particles were sinking through the water column during the single measurement cycle, and that the sampling period of 10 minutes represents currents during the sinking period of half an hour. It is estimated that the range of sinking speed is larger due to the unknown densities of the water column, food pellets and faecal particles, and due to the unknown geometry of the latter during the entire measurement period.

We may reasonably suppose that food pellets and faecal particles of density ρ_p are sinking laminarly with a constant speed within a layer of a constant density ρ. In the balance of forces that act on sinking particles, a problem arises with the friction force, since the geometry of food pellets and faecal particles is not sufficiently known. However, we may qualitatively describe the linear friction law (Kundu, 1990) that holds for the low Reynolds numbers ($Re = vd/\eta$, where v is the sinking speed, d the typical dimension across the particle, and $\eta = 10^{-6}$ m^2 s is the kinematic viscosity at 20 °C). It is estimated that Re is smaller than 300 for food pellets (v = 0.06 m/s and $d < 5\ 10^{-3}$ m), and that Re is below 13 (v = 6.4 10^{-3} m/s and $d < 2\ 10^{-3}$ m) for faecal particles. This indicates that the linear dependence of friction force on the sinking velocity is applicable and the friction force is parameterised as $K\rho_p\ \eta\ d\ v$, where K is the dimensionless constant that accounts for geometry ($K = 6\ \pi$ for sphere-like particles). The balance between the buoyancy force ($\rho_p - \rho$)gV (g = 9.81 m/s^2 is the gravity acceleration and V the volume of a particle), and the friction force yields the sinking velocity as:

$$v = \frac{\left(\rho_p - \rho\right)gV}{K\eta\rho d}.$$

This means that if the density of a sinking particle ρ_p is known, the sinking speed is decreasing with the ambient density in an inverse linear way, proportional to $1/x - \rho_0/\rho_p$, where $x = \rho_0/\rho$ is the ratio of densities, with ρ_0 being the density at which the sinking speed was measured. The density is related to the density excess σ_T as $\rho = 1000.0 + \sigma_T$. Tab. 1 shows that over the period of 25 years σ_T in the Bay of Piran has varied for less than 10.2 kg/m^3, x therefore for less than 1%, and so has the sinking speed due to variations of the ambient density. There are no estimates as to the density variations of particles, which are probably much higher for faecal particles. Their volume also affects the sinking velocity. There are, however, no estimates of volume variations that could vary significantly with the age of fish population, and also of the food supply type. It is expected, however, that the volume of food pellets does not vary that much.

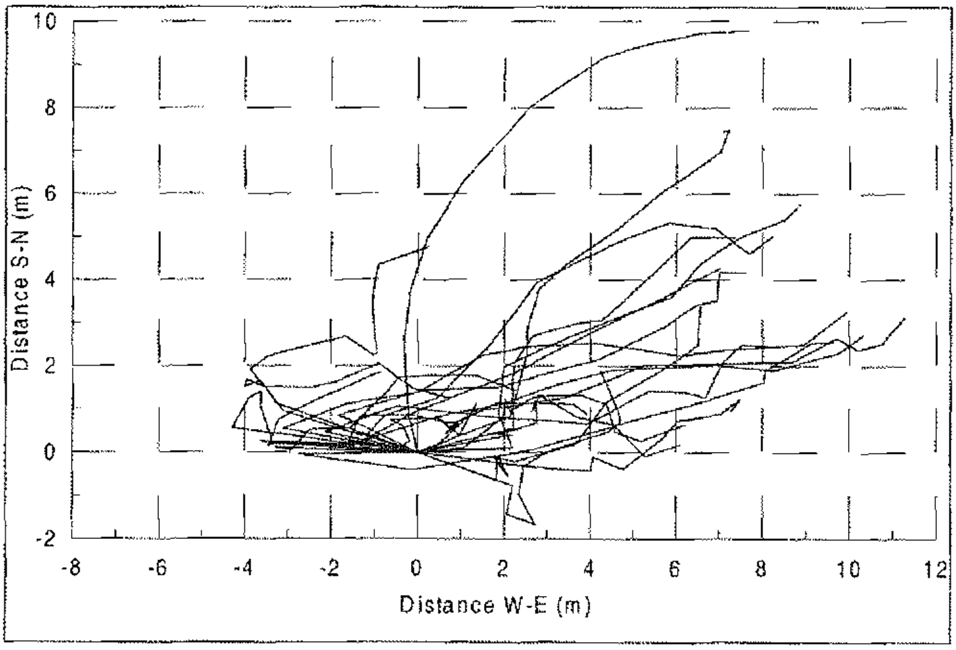

Fig. 2: Trajectories of fish food driven by currents for selected 24-hour measurements (21 June, 2000), if the particles were released hourly.
Sl. 2: Poti namišljenih delcev ribje hrane kot posledica tokov med 24-urnimi meritvami 21. junija 2000 in končni položaj teh delcev na morskem dnu. Delci so bili izpuščeni v intervalu ene ure.

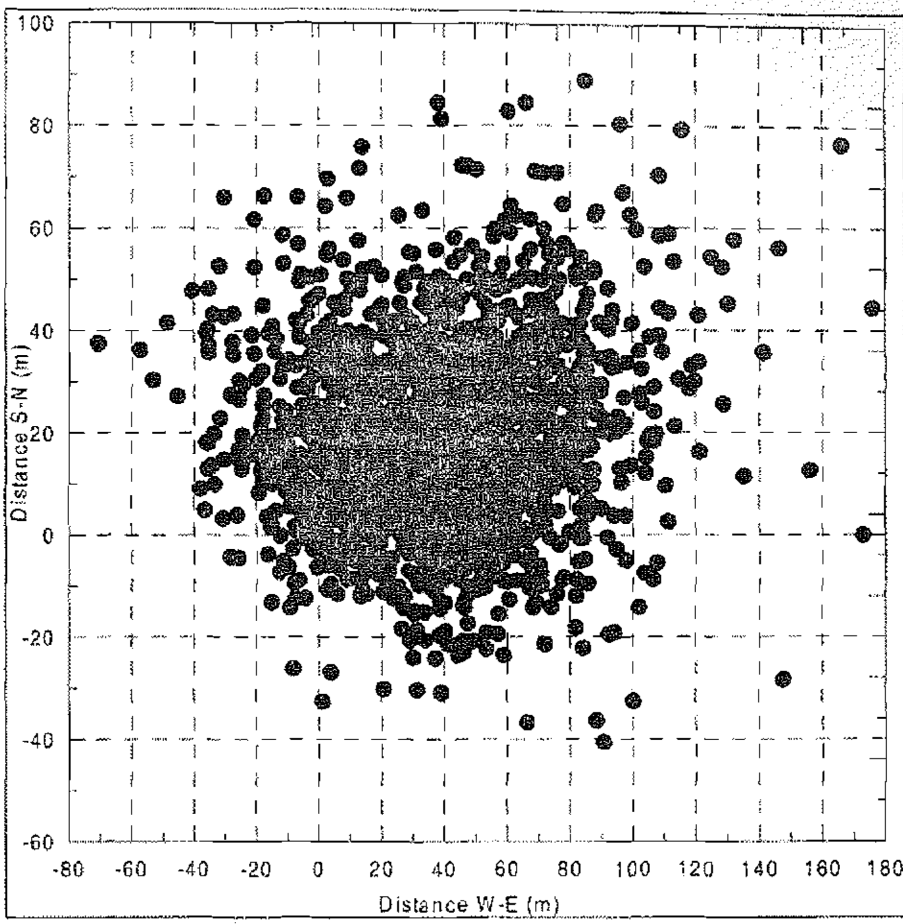

Fig. 3: Simulated distribution of faecal particles on the seabed using trajectories data from the currents measured between April 19 and June 21. The sinking velocity was 0.64±0.05 cm/s.
Sl. 3: Simulacija razporeditve delcev ribjih iztrebkov na morskem dnu. Poti so bile izračunane na osnovi dvomesečnih meritev tokov od 19. aprila do 21. aprila 2000. Hitrost tonjenja je bila 0.64±0.05 cm/s.

Figure 2 displays the trajectories of food particles and their distribution on the sea floor from beneath the centre of a fish farm, if food pellets were released hourly within 24 hours of 21 June 2000. Food particles were spread over a patch covering an area of 16 x 12 m, no more than the fish farm itself. Since the sinking velocity for faecal particles is roughly for an order of magnitude smaller, a similar plot would indicate that the scale of distribution would cover an area around 160 x 120 m. Since during the summer period currents were evenly distributed in all directions, the simulation has been conducted for the spring period, when it was expected that the spread of particles at the sea floor would be larger. Figure 3 shows a simulation of the distribution of food particles if they were released hourly during the late spring period when currents were measured. Sinking food covers an area smaller than 30 x 15 m, indicating that the distribution of faecal particles is within the range of 300 x 150 m.

Measurements of currents on the fish farm site and lab measurements of settling velocity of food pellets and faecal particles have been combined with the simulation of their distribution on the sea floor beneath the fish farm. While many important parameters are missing, such as the variation of density and volume of the particles, it is expected that a reasonable first estimate of patches of food surplus and faecal material has been achieved. Both of them cover an area that is smaller in diameter than a few 100 m. We may therefore consider them as those pointwise pollutants of fish farming that do not affect the ambient of this range. This conclusion, however, is not applicable for the dissolved organic matter generated by fish farming.

RAZPRŠITEV RIBJE HRANE IN IZTREBKOV NA DNO POD RIBOGOJNICO V PIRANSKEM ZALIVU

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POVZETEK

Iz meritev tokov in laboratorijskih meritev hitrosti tonjenja ribje hrane in delcev ribjih iztrebkov je bila narejena simulacija njihove razpršitve. Pokazalo se je, da višek hrane pokrije površino, manjšo od 30 x 15 m, medtem ko iztrebki ostanejo znotraj meja 300 x 150 m.

Ključne besede: marikultura, tokovi, okolje, Piranski zaliv

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