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Dependence of beach seine net efficiency on net length and diel period

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Abstract – The aim of this study was to quantify the efficiency of different lengths of beach seine nets for each diel period in freshwater reservoirs. Only fish older than young-of-the-year were considered. Nets of 10, 20 and 50 m length ("in-nets") were tested in an enclosed area framed by a 200 m long net (block net). The net efficiency estimate was calculated as the ratio of fish catches with the in-net and block net divided by the ratio of their respective areas. The net efficiency estimate was significantly different between day and night catches. At night, the efficiency estimate of nets depended on the size of the fish. The efficiency estimate of a 10 m long net decreased significantly in reverse correlation with fish size. A similar trend was found when using a 20 m long net. The efficiency estimate of a 50 m long net was independent of fish size. The variance in efficiency estimate between samples with a given net length was high, but decreased with longer nets. Of five species tested, only the efficiency estimate for catching bream (*Abramis brama*) increased significantly with the length of net. The biomass and abundance of larger fish was generally higher at night, although especially short nets exhibited a spuriously high efficiency estimate during the day, probably due to the concentrating (chasing) effect of the hauling ropes. We therefore recommend the use of a 50 m long net, since its nighttime efficiency estimate was about 0.9 in terms of both sampling abundance and biomass. A model relating the efficiency estimate and net length was developed with the data acquired.

Key words: Beach seine net / Net length / Efficiency estimate / Size selectivity / Freshwater fish / European reservoir

Résumé – L'efficacité des sennes de plage dépend de la longueur du filet et de la période du jour et de la nuit. L'objective de cette étude est de quantifier l'efficacité de sennes de plage de différentes longueurs et à différentes périodes de la journée (nuit-jour). Seuls les poissons âgés d'un an et plus sont considérés ici. Des filets de 10, 20 et 50 m de longueurs sont testés dans un enclos fermés par un filet-barrage de 200 m de long. L'estimation de l'efficacité du filet testé est calculée par le rapport des captures de poissons dans le filet sur celles du filet-barrage divisé par le rapport de leur surface respective. L'estimation de l'efficacité du filet est significativement différente entre les captures effectuées de jour et celles de la nuit. De nuit, l'estimation de l'efficacité dépend de la taille du poisson. L'efficacité d'un filet de 10 ou de 20 m de long est inversement corrélée avec la taille des poissons. L'efficacité d'un filet de 50 m est indépendante de la taille des poissons. La variance de l'estimation de l'efficacité entre les échantillons est grande pour un filet de longueur donnée mais la variance décroît avec des filets plus longs. Des 5 espèces testées, seules les captures de brèmes (*Abramis brama*) augmentent significativement avec la longueur du filet. La biomasse et l'abondance de poissons de grandes tailles sont généralement plus élevées la nuit, bien que des filets courts présentent faussement une grande efficacité de jour, probablement due à la concentration des cordages de halage. Ainsi, nous recommandons l'usage de senne de 50 m de long, l'efficacité de captures nocturnes est estimée à 0,9 en terme d'abondance et de biomasse. Un modèle reliant l'estimation de l'efficacité et la longueur du filet est développé à partir des données acquises.

1 Introduction

Beach seining is a very effective method for sampling the assemblage of littoral fish, as it has several advantages over other techniques (Pierce et al. 1990; Prchalová et al. 2008a). Although seine nets have been used by fishermen since antiquity, and for scientific and management purposes for more than a century, most researchers still do not know the relationship

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between their catch and the actual abundance or size distribution of fish in a defined area (Bayley and Herendeen 2000).

The efficiency of seine nets has been studied by a number of authors who showed that it may depend on the species and size composition of a fish community, environmental conditions such as the heterogeneity of the littoral area (e.g. macrophyte cover or bottom substrate), or diel and seasonal period (Lyons 1986; Parsley et al. 1989; Pierce et al. 1990; Allen et al. 1992; Holland-Bartels and Dewey 1997; Bayley and Herendeen 2000). Lyons (1986) also noted that seine technique and design affected the efficacy of this method. There is a lack of information about the influence of net length, a very important design feature, on the efficiency of the method (DeLacy and English 1954; Steele et al. 2006). Studies done by Allen et al. (1992) and Bayley and Herendeen (2000) showed that the seine net is less efficient for larger or faster fish species. We suppose that these observations may be due to the length of the net. Thus net efficiency may increase with net length because fish have a potentially lower probability of escape. This assumption also suggests that use of a longer net will give more representative results.

On the other hand, use of seining requires specific conditions such as a bottom surface with a slight slope but without obstructions, extensive amounts of mud or submerged macrophytes. The manpower required for net handling increases with length. These demands call for the use of shorter nets and imply there is a trade-off between the feasibility of seining and the degree to which results are representative.

It is also likely that seine net efficiency varies through the diel period because fish have a different response to sampling gear between day and night (Wardle 1993). Therefore, we expect that efficiency and usability of certain lengths of net could also be dependent on sampling time.

The aims of this study were i) to quantify the night and day efficiency estimates of three net lengths commonly used in fish abundance and biomass sampling and ii) to compare sample size between shorter and longer nets within each diel period. In addition, the differences in total abundance and biomass of fish in day and night samples were compared.

2 Materials and methods

2.1 Study area

The study was carried out on three Czech reservoirs: Římov, Želivka and Orlík. The Římov Reservoir (48°50′59.672″N, 14°29′27.463″E) has a surface area of 210 ha, a volume of 33×10^6 m^3, and its maximum and mean depths are 45 m and 16 m, respectively. The length of the reservoir is 12 km and its maximum surface altitude is 471 m above sea level. The Želivka Reservoir (49°43′29.63″N, 15°5′18.867″E) has a surface area of 1432 ha, a volume of 246×10^6 m^3, and its maximum and mean depths are 55.7 m and 17 m, respectively. The length of the former riverbed is 38 km, and the maximum surface altitude is 380 m. The Orlík Reservoir (49°36′22.274″N, 14°10′53.447″E) has a surface area of 2637 ha, a volume of 703.8×10^6 m^3, and its maximum and mean depths are 72 m and 26 m, respectively. The length of the reservoir is 55 km. These reservoirs are dimictic, with well-developed thermal stratification in summer. The fish community of these reservoirs is dominated by zooplanktivorous cyprinid species (Vašek et al. 2003; Kubečka et al. 2006; Prchalová et al. 2008b).

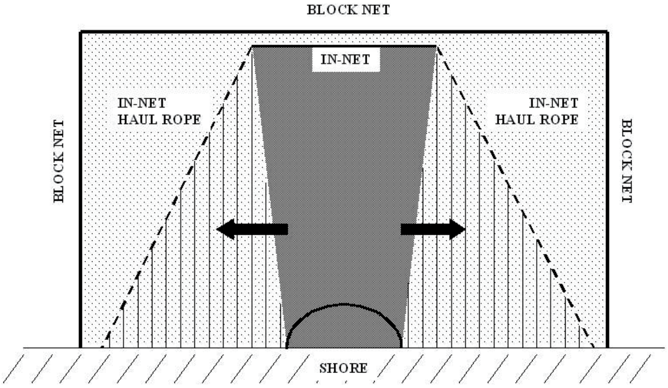

Fig. 1. Diagram of the sampling operation. Initially, the block net was used to define the sampling area. The net was spread to create a rectangle from the shoreline to the open water (to isobaths of 3.5–4 m). Subsequently, one of the in-nets was laid out in the enclosure area using a boat parallel to the shore and as close as possible to the block net. The in-net was then hauled to the shore. The enclosure area (A_{BN}) defined by the block net was precisely measured using a measuring tape and the block net was then carefully hauled to the shore. *In grey*: area hauled by the in-net (A_{IN}). *Stipple*: area hauled by the block net (A_{BN}). *Dashed lines*: positions of the in-net haul ropes at the start of net hauling. *Semicircle*: position of in-net when both of its ends reach the shore. *Arrows*: assumed swimming direction of escaping fish. *Vertical lines*: area where the concentrating (chasing) effect of hauling ropes took place during the day.

2.2 Sampling

Sampling was conducted on suitable shores with a slight slope (2–8°) and a bottom surface consisting of a fine substrate without mud or obstructions. No submerged aquatic macrophytes were present at the sampling sites.

Three different lengths of nets were used: 10, 20 and 50 m, herein referred to as “in-nets”. Each consisted of simple wall of netting, with a width of 4 m, mesh size of 10 mm (knot-to-knot), floats on the top line and lead weights on the bottom line. The floats were 16 × 7.5 cm cylindrical polystyrene, attached every 55 cm on the top line. The haul ropes were 50 m long and attached to the each side of the net.

A block net was also used, which was 200 × 4 m in area, with a 10 mm mesh size and the same design of floats and lead line as the in-nets. The block net was spread first to define the sampling area. It was spread to create a rectangle from the shoreline to the open water (to isobaths of 3.5–4 m) (Fig. 1), using a rowing boat so as not to disturb fish in the chosen sampling area. The Eagle Ultra Classic echosounder was used to measure depth while setting the net. One of the in-nets was subsequently laid out in the enclosure area, again using the boat, in parallel with the shore and as close as possible to the block net. It was then pulled to the shore with the haul ropes (Fig. 1), making sure that the bottom and float lines were properly positioned to prevent fish from escaping. The enclosure

Table 1. Sample summary – number of samples, mean sampled area (MSA) by in-net and block net and total abundance and biomass of the fish captured during sampling.

	10 m	20 m	50 m
Day			
No. of samples	10	10	10
MSA by in-net (m^2)	189	469	1222
MSA by block net (m^2)	1084	1861	2754
Abundance of fish (ind.)	861	2562	6184
Biomass of fish (kg)	33.4	63.4	146.7
Night			
No. of samples	18	18	17
MSA by in-net (m^2)	214	510	1125
MSA by block net (m^2)	1241	1550	2127
Abundance of fish (ind.)	4423	6323	7248
Biomass of fish (kg)	259.3	366.0	444.4

area (A_{BN}) was defined by the block net, as measured using a measuring tape. The fish catches using both methods were recorded, excluding samples from hauls in which the net became snagged.

The experiments were done during the day (30 hauls) and at night (53 hauls) (Table 1), during the summer season from June to August. They were carried out in the years 2003, 2005 and 2006 at the Římov Reservoir, 2004 at the Orlík Reservoir and 2004 and 2005 at the Želivka Reservoir.

Net efficiency estimate (*EE*) was calculated according to the equation:

$$EE = \frac{C_{\mathrm{IN}}/C_{\mathrm{T}}}{A_{\mathrm{IN}}/A_{\mathrm{BN}}}$$

The catch from the in-net (C_{IN}) was divided by the total catch from the enclosure area (C_{T}), (i.e. the sum of the in-net and block net). It was not possible to keep the same ratio of sampled areas between the in-net (A_{IN}) and the block net (A_{BN}) so their area ratio was taken into account in the calculation. The efficiency estimate of the in-net could therefore theoretically exceed one (i.e. 100%), meaning that the in-net had caught a greater amount of fish than was proportional to its sampled area. For example, if the in-net catch contained 50% of all fish from the enclosure but its sampled area was just 30% of the enclosure area, then the EE value would be 1.67. This would mean that the in-net catch contained 1.67 times more fish than it should catch with respect to the area it sampled.

The net efficiency estimate of night samples was calculated for each of the following parameters:

- Abundance and biomass of all species together;
- Three size categories of fish: 5–10 cm, 10–20 cm, larger than 20 cm;
- Particular species, bream (*Abramis brama*), roach (*Rutilus rutilus*), perch (*Perca fluviatilis*), bleak (*Alburnus alburnus*) and ruffe (*Gymnocephalus cernuus*).

For day samples, net efficiency estimates were only calculated in terms of the abundance and biomass of all species. Efficiency estimates for individual species were not calculated in day samples due to the extremely high variance of individual species they contained. Similarly, efficiency estimates for individual size categories could not be assessed during the day because the numbers of fish >10 cm were insufficient.

In addition, we calculated the number of hauls needed with a shorter net to obtain the same number of fish as one haul with a longer net (the formula is described in the following statistical analysis section). In the night catches, this number was evaluated for total abundance, biomass and all fish size categories. In the catches made during the day, it was evaluated for total abundance and biomass only.

All fish caught were identified to the species level, measured to 5 mm accuracy and weighed. Any catch of 0+ fish was ignored. All the results were expressed for 1+ and older fish.

2.3 Statistical analysis

We initially compared the variance of the efficiency estimates of different net lengths using the Bartlett test to determine whether variances were equal across samples. The results clearly showed diverse variances between hauls for each net category. We could not therefore use ANOVA and instead used the generalized least square method (GLS) to compare efficiency estimates. In contrast to ANOVA, GLS evaluates data variance in each group separately before their comparison. The GLS analyses had one or two factors. Net length was a factor in every analysis. In the case of comparison of size categories and comparison of day and night efficiency estimates, size category or diel period was used as the second factor. Only samples with five or more individuals of particular species or size categories in the enclosure area were included in the analysis. The purpose of this methodology was to reduce the influence of samples with small numbers of fish.

Non-linear regression was used for modeling night efficiency estimates of nets for different fish size categories. We only had information about the efficiency estimates of 10, 20 and 50 m nets, so non-linear regression helped us to predict the efficiency estimates for other untested net lengths. Three models were chosen according to Mrkvička and Petrášková (2006) and Forthofer et al. (2007), and tested. The equations were as follows:

$$\text{Model 1}: EE = -\frac{a + c \times \ln(net\ length)}{b - c \times \ln(net\ length)}$$

$$\text{Model 2}: EE = \frac{Exp\,[a + b \times net\ length]}{1 + Exp\,[a + b \text{ x } net\ length]}$$

$$\text{Model 3}: EE = a \times \ln\,[b \times net\ length]$$

where *a*, *b* and *c* are parameters. An assumption of all of these models is that efficiency estimates increase asymptotically up to the value of 1, i.e. that a net of infinite length has an efficiency estimate of one. Parameters of the models were tested by the least square method. The model with the best R^2 parameters was then selected.

The number of hauls (*NH*) of the shorter net needed to obtain the same number of fish as with one haul with the longer net was calculated according to equation:

$$NH = E\left(\frac{EE_{\mathrm{LN}} \times A_{\mathrm{LN}}}{EE_{\mathrm{SN}} \times A_{\mathrm{SN}}}\right)$$

which is equal to $NH = E\left(\frac{EE_{\mathrm{IN}}}{EE_{\mathrm{SN}}}\right) \times \left(\frac{A_{\mathrm{IN}}}{A_{\mathrm{SN}}}\right)$, because $\left(\frac{A_{\mathrm{IN}}}{A_{\mathrm{SN}}}\right)$ is not considered as a random variable. Here E is the expectation,

EE_{LN} is the longer net efficiency estimate, A_{LN} is the mean area sampled by the longer net, EE_{SN} is the shorter net efficiency estimate and A_{SN} is the mean area sampled by the shorter net. The equation was calculated in two steps. First, the expectation of efficiency estimate ratio was calculated. The simple ratio of the mean efficiency estimates is biased and we did not have information about its real distribution. We therefore used an unbiased resampling method according to Manly (1997) and Poos et al. (2007). This resampling method was based on the sampling with replacement of the measured data following calculation of the ratio from these sampled values. We randomly chose one efficiency estimate from the longer net. Then we randomly chose as many efficiency estimates for the shorter net as were needed to obtain approximately the same value as for the longer net. This operation was repeated 10 000 times and the mean of the calculated ratios gave the final ratio of efficiency estimates. This value was then used in a second step in which it was multiplied by the ratio of the mean sampled areas to obtain the number of hauls. The number of hauls is equal to the simple ratio of the sampled area of the longer and the shorter nets if the efficiency estimate of the shorter and longer nets is equal. The value increases if the efficiency estimate of the shorter net is lower than the efficiency estimate of the longer net or vice versa.

The diel differences in total abundance and biomass in catch were tested by two-way ANOVA. The total catch (in-net + block net) was used for this analysis. Each sample was standardized to the same unit of area (ind.ha^{-1} and kg ha^{-1} for abundance and biomass, respectively) before analysis. The first factor was the diel period and the second factor was the reservoir. We tested only the effect of the diel period and the reservoir was used as a covariate.

3 Results

3.1 Night efficiency estimate and conversion between sample size of different seine net lengths

The mean efficiency estimates for abundance of catches with the three net lengths ranged from 0.85 to 0.93, and did not differ significantly (Fig. 2). The mean efficiency estimate in terms of biomass was considerably lower for the 10 m net compared with the 20 m and 50 m nets, which had similar efficiency estimates. The difference between the longest and shortest nets was almost significant ($p = 0.058$) (Fig. 2).

The efficiency estimate of the 10 m net decreased significantly with fish size ($p < 0.001$, Fig. 3), being less efficient for fish > 20 cm than the other nets ($p = 0.004$). The mean efficiency estimate of the 20 m net also decreased with fish size, but the differences between the fish size categories were not significant ($p = 0.42$, Fig. 3). The decreasing efficiency estimate due to larger fish sizes for the 50 m net was not significant either ($p = 0.47$, Fig. 3).

Model 1 had the highest R^2 parameters and was chosen to determine the efficiency estimate of all three net types in relation to fish size categories: 10–20 cm and bigger than 20 cm (Fig. 4). This asymptotic model was not applied to the smallest size category (5–10 cm) because the mean values of the efficiency estimate decreased with net length (mainly due to high variability of efficiency estimate with the shorter nets, Fig. 3). Thus, the net efficiency estimate with this size category was modeled by a constant value (mean efficiency estimate, 0.95, of all nets in this size category). The parameters entered into the model and resulting calculated efficiency estimates are given in Table 2, with the R^2 parameters of the other models tested (Model 2 and 3). The chosen model revealed a dramatic increase in the efficiency estimate of the 10 to 20 m nets for fish longer than 10 cm. The efficiency estimates and model values for the 20 m and 50 m nets were similar.

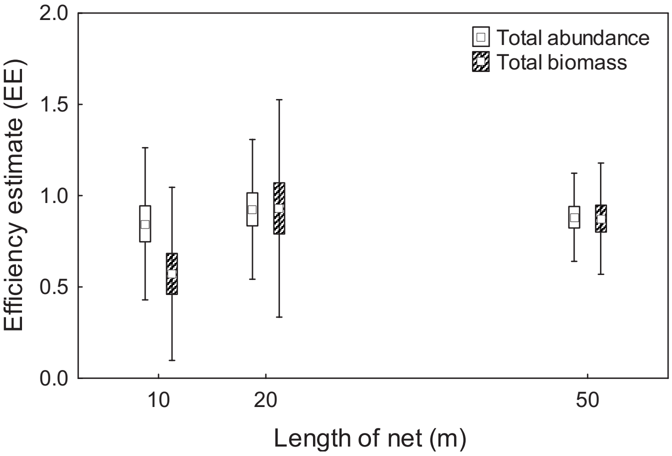

Fig. 2. Night efficiency estimate (*EE*) of 10 m, 20 m and 50 m long beach seine nets in terms of abundance and biomass of fish; boxes indicate standard error, whiskers standard deviation.

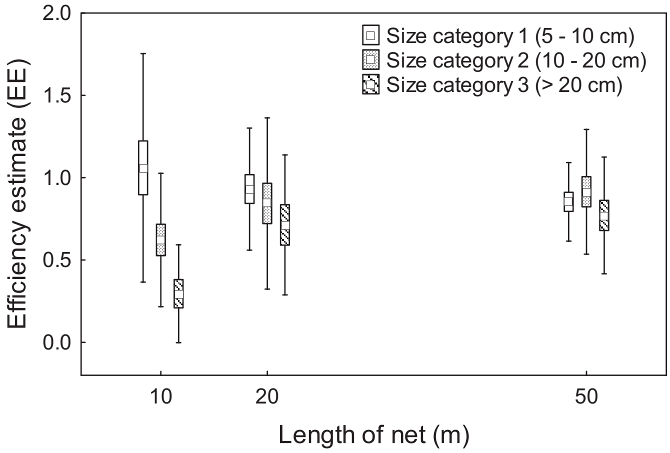

Fig. 3. Night efficiency estimate (*EE*) of 10, 20 and 50 m long beach seine nets for different fish size categories; boxes indicate standard error, whiskers standard deviation.

Statistically significant differences were found in the amplitude of variance of *EE* between net lengths, both for biomass ($p = 0.036$) and different size categories ($p < 0.000$). Variance decreased as net length increased in both cases (Figs. 2 and 3). A similar trend was also observed for the variance of abundance, but was not statistically significant ($p = 0.091$).

Out of all the species tested, differences in the net efficiency estimate were only significant for bream (abundance

Table 2. Model 1 efficiency estimate parameters and correlation coefficients (R^2) of 10 m, 20 m and 50 m beach seine nets in relation to fish size categories. A constant value was used as a model of efficiency estimate for the first (5–10 cm) size category. R^2 values of the other tested models are also shown. All models were based on data from night seining.

	Model 1 efficiency estimate of net			Model 1 parameters			R^2 of other tested models		
Category	10 m	20 m	50 m	*a*	*b*	*c*	R^2	Model 2	Model 3
Size 5–10 cm	0.950	0.950	0.950					–0.011	0.000
Size 10–20 cm	0.622	0.845	0.913	304.942	277.219	152.254	0.078	0.068	0.068
Size > 20 cm	0.300	0.675	0.810	42.2463	33.8744	19.9077	0.259	0.145	0.207

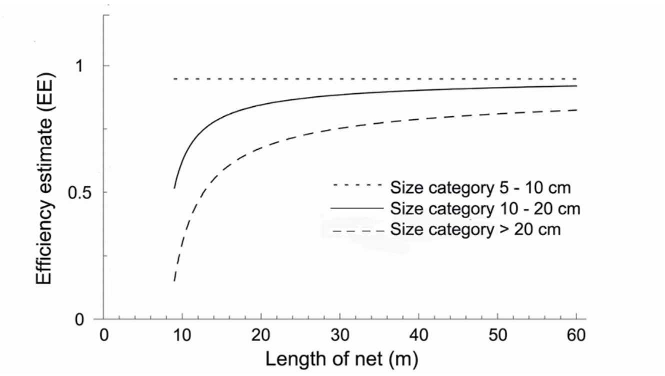

Fig. 4. Model of the night efficiency estimate (*EE*) of the beach seine net in relation to different fish size categories.

Table 3. The number of hauls by a shorter net needed to obtain the same number of fish as by one haul of a longer net. If the efficiency estimate between shorter and longer nets is equal, the number is equal to simple ratio of their sampled area. However, the number increases if the efficiency estimate of shorter net is lower than the efficiency estimate of longer net, and decreases if the efficiency estimate of the shorter net is higher than the efficiency estimate of the longer net.

	Shorter net → Longer net		
Category	10 → 20	10 → 50	20 → 50
Day			
Total abundance	2.9	3.4	1.8
Total biomass	2.5	4.2	2.0
Ratio of sampled areas	2.5	6.5	2.6
Night			
Fish size 5–10 cm	2.5	5.1	2.2
Fish size 10–20 cm	3.6	8.8	2.8
Fish size > 20 cm	6.9	16.2	2.8
Total abundance	2.8	6.0	2.3
Total biomass	4.6	9.7	2.5
Ratio of sampled areas	2.4	5.3	2.2

$p < 0.002$; biomass $p < 0.000$). The trend of increasing efficiency estimate with longer nets was also apparent for roach, although it was not statistically significant (Fig. 5a,b).

The 10 m net required a higher number of hauls (in comparison with the ratio of sampled areas) than the other nets to obtain the same number of fish at night (Table 3). These differences were apparent for parameters in which the 10 m net had a low efficiency estimate (fish > 10 cm, total fish biomass; Table 3).

3.2 Day efficiency estimate and conversion between sample size of different seine net lengths

Significant differences in efficiency estimate between nets for day seining were observed in terms of abundance ($p = 0.006$). Surprisingly, the efficiency estimate exceeded a value of one in the short nets (10, 20 m) and decreased with the length of net (Fig. 6). The efficiency estimate in terms of biomass displayed a similar trend, although the observed differences were not significant ($p = 0.201$, Fig. 6). Statistically significant differences were found between nets for the variance of efficiency estimate for both abundance ($p = 0.011$) and biomass ($p = 0.019$). As with night seining, the variance between samples was reduced with increased net length.

The enhanced daytime efficiency estimate of short nets resulted in less hauls being needed to obtain the same number or biomass of fish corresponding to the ratio of sampled areas (Table 3).

3.3 Night vs. day differences in efficiency estimate, total fish abundance and biomass

The efficiency estimate for fish abundance was higher during the day than at night ($p < 0.001$). The differences were mainly seen between the 10 and 20 m nets. For the 50 m net, the night and day efficiency estimates were similar. No significant differences were found in terms of biomass ($p = 0.124$).

The total abundance of fish in samples was similar during the day and night ($p = 0.736$), while total fish biomass was on average 3.6 times higher at night ($p < 0.001$).

4 Discussion

Our study has shown that the efficiency estimate of a seine net depends on its length, and that this dependence varies with diel period as well as fish size and species. Efficiency estimates were seen to increase with net length during night hauls. However, during the day, the efficiency estimate decreased with net length. The 50 m net was found to be the most representative for sampling.

The dependence of efficiency on net length has been reported in a number of studies (DeLacy and English 1954; Steele et al. 2006). Our findings are in agreement with the study by DeLacy and English (1954). These authors found that a longer net (39.8 m) gave a more representative picture of a littoral fish community with a high occurrence of bigger and

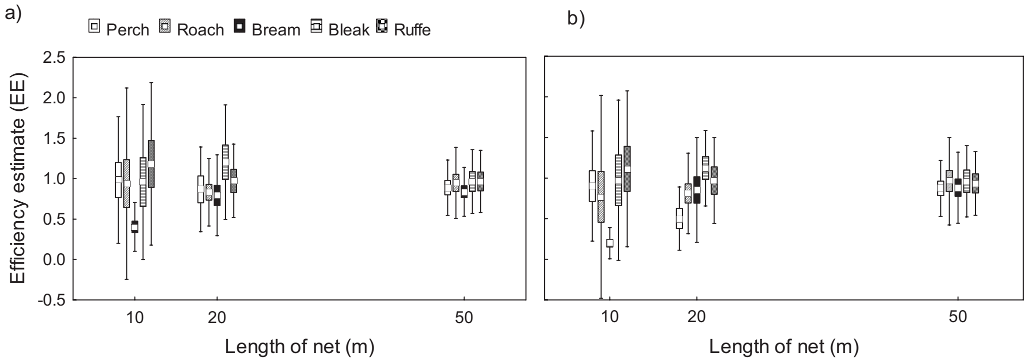

Fig. 5. Night efficiency estimate (*EE*) of 10, 20 and 50 m long beach seine nets in relation to abundance (*a*) and biomass (*b*) of individual species; boxes indicate standard error, whiskers standard deviation.

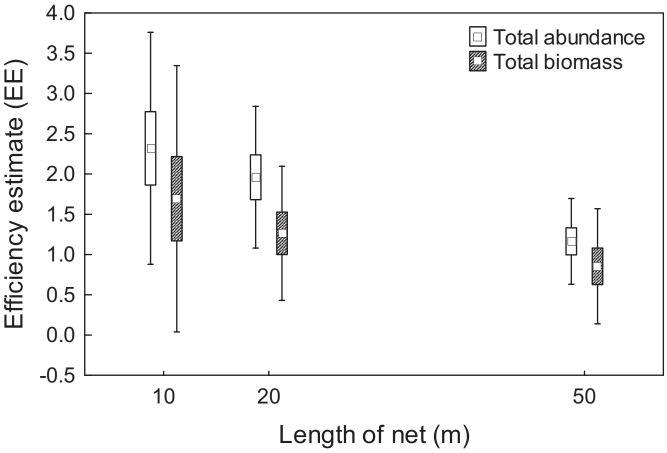

Fig. 6. Day efficiency estimate (*EE*) of 10, 20 and 50 m long beach seine nets in relation to abundance and biomass; boxes indicate standard error, whiskers standard deviation.

more active fish, than did a shorter net (19.8 m). On the other hand, Steele et al. (2006) compared fish species composition with two shorter nets (7.6 and 15.2 m). They found that the shorter net was more efficient due to increased catches of demersal species, which occurred because the lead line of the shorter net had better contact with the bottom than that of the longer net. Their results also contrast with our findings because their fish community was different from the ones we sampled, with many demersal and small estuarine species.

A significant influence of species-specific behaviour on the efficiency of the seine net has been reported by many authors (Lyons 1986; Pierce et al. 1990; Allen et al. 1992; Holland-Bartels and Dewey 1997; Bayley and Herendeen 2000; Gray et al. 2000), as have differences in efficiency for different net size categories (Allen et al. 1992; Bayley and Herendeen 2000). Our findings show that species and size selectivity of seining can be partly reduced by the use of a longer net.

The estimate of efficiency assumes low fish avoidance during hauling of the block net. We assume that on smooth seining beaches, avoidance along the ends of the net before reaching the shore (arrows on Fig. 1) is more prevalent than under the bottom line of the block net, which conforms to the reservoir bottom (directly observed during scuba diving). Block net efficiency was examined in a number of previous studies (e.g. Charles-Dominique 1989; Pierce et al. 1990; Steele et al. 2006). Pierce et al. (1990) showed that under optimal conditions, the efficiency of the block net approached 100%. We carried out all our experiments on suitable beaches with no submerged macrophytes, and hauls with snags were not included into our analyses. These provisions allowed optimal conditions for the highest efficiency of the block net.

Another important assumption of our approach is the homogeneity of fish stock in the whole area surrounded by the block net. The littoral area can be a heterogeneous environment and various species may prefer different microhabitats; they may consequently exhibit variable microdistribution (Fischer and Eckmann 1997; Lewin et al. 2004; Winfield 2004). We took great care in selecting homogeneous sampling beaches with no apparent structures. However, fish microdistribution is likely to have influenced the catch of short nets, while increase in the hauled area reduced the patchiness effect. This effect would mainly cause high variably in efficiency estimates of short nets, perhaps partially explaining why the efficiency estimates exceeded the value of one in some samples.

The efficiency estimate of nets of different lengths was dependent on fish size during night sampling. All nets had a similar efficiency estimate for small fish (5–10 cm) catches. Larger fish (>10 cm) were underrepresented in the 10 m net. The 10 and 20 m nets exhibited the biggest difference of efficiency estimate for catches of larger fish. The difference between net efficiency estimates of 20 and 50 m nets was marginal.

We suggest that fish avoidance is one factor that significantly contributes to the underestimation of certain fish sizes. Successful evasion of capture is correlated with the swimming speed and body size of fish (Rudstam et al. 1984; Anderson 1998; Jepsen et al. 1999). The remarkably high increase in efficiency estimate between 10 and 20 m lengths could be explained by the direct response of fish to these types of nets. Wardle (1993) described a phenomenon in which fish enclosed by a benthic trawl net did not escape but rather swam in front and in the same direction as the net. We observed similar swimming behaviour of fish while diving during night seining (M. Říha, unpubl. data). Gray et al. (2000) observed fish behavior during day seining: the fish were enclosed by the net, and herded in front during hauling. However, when the net came into proximity with the beach, the fish became more active and swam in all directions. We suspect there was a similar reaction from the species sampled in our study. In this final phase of hauling, the fish have only a short time to escape from the net. The probability of successful escape is dependent on the position of the fish with respect to the length of net and on their swimming direction. The escape distance from the 10 m net is relatively short from all positions. Also, if there is a "threshold depth" for initiating avoidance behavior, the ends of the longer nets may have already been closed ashore before most of fish reached the "threshold depth". The 10 m net is obviously too short in this respect. Escape distance for the 20 m net is twice as long as that of the 10 m net. This length seems sufficient for retaining quite a high portion of larger fish. On the other hand, the mean efficiency estimate of the 20 m net was similar to that of the 50 m net, although it exhibited wider variance between samples.

Efficiency estimate during the day was significantly higher than at night, decreasing with the length of net. However, we expected the opposite trend because fish can see a net sooner in daylight and thus lower the efficiency (Wardle 1993). The haul ropes were probably the cause of the spuriously drastic decrease in efficiency estimate with increasing net length. It is possible that the hauling ropes drove fish from the outside to the middle of the haul (Fig. 1). Our data indicate a spurious increase of the efficiency estimate of short nets because the proportion of area "hauled" or disturbed by ropes, relative to the area fished (A_{IN}), was the highest with the 10 m net. The proportion decreased with the more extensive A_{IN} of the longer nets. It is difficult to say whether the observed efficiency estimate of day seining indicates that it is more advantageous for sampling. The daytime inshore assemblage lacked larger fish (see below) and the chasing effect of the hauling ropes could be species specific and dependent on water transparency, type of rope, etc.

Our results have shown that only bream had significantly better escape behavior than other species. Bream are active mainly during the day (Schulz and Berg 1987), but are well adapted to turbid conditions (Olin et al. 2002). One explanation of this better escape behavior is that bream inhabited deeper parts of the sampled areas and/or that they were able to sense nets sooner, on average, than other species. The other explanation is that bream had more active avoidance reactions after disturbance than other species (M. Říha, unpubl. data from scuba observations).

Although nets could appear more efficient during day seining (Figs. 2 and 6), night seining was more representative of the fish community. Small-sized fish comprised a considerable part of the catch in terms of abundance, both in the day and at night, but their contribution to the biomass was not great. Total biomass increased with the migration of bigger (adult) fish to the littoral area at night. Such behavior patterns have already been observed for different species by Schulz and Berg (1987), Kubečka (1993) and Zamora and Moreno-Amich (2002).

Seining can obviously only be performed on a relatively smooth bottom surfaces (Hayes et al. 1996) without too much mud or submerged macrophytes (Pierce et al. 1990). It is very important to seek and maintain these optimal conditions for reliable quantitative sampling. Snagging and subsequent desnagging could cause the escape of fish in an unpredictable manner (Pierce et al. 1990). However our experience shows that smooth-bottomed surfaces can be found in most water bodies, and that in such conditions the 50 m net at night exhibited a very reasonable efficiency estimate for all fish sizes, thus facilitating the reliable measurement of fish stock densities.

5 Conclusion

The results of this study can be of help to other scientists and managers for the selection of appropriate net lengths and the understanding of their limitations. The 10 m net underestimated biomass and abundance of larger fish (>10 cm), as well as bream, during night sampling. This net was spuriously more efficient during day and its efficiency estimate and absolute catch were highly variable during both periods. The 10 m net is only useful for the sampling of small fish (up to 10 cm). The 20 m net had a mean efficiency estimate similar to the 50 m net, but its efficiency estimate and catch size were still highly variable. Finally, the 50 m net appeared to be the best for routine sampling. It exhibited a very similar mean efficiency estimate for all characteristics and the lowest variance. A model predicting the seine net efficiency estimate according to the length of nets for different fish sizes was developed. It is possible to correct the abundance and biomass using efficiency estimates from the model. The best option for quantitative sampling is to enclose the entire sampling area with a net (similar to the block net on Fig. 1; without using an in-net). Enclosing the entire sampling area obviously requires much longer nets (three sides of sampled area need to be netted instead of just one) and is more labour-intensive and costly per unit of sampled area.

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