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# Comparisons of two research vessels' properties in the acoustic surveys of small pelagic fish

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*Acoustic surveys in the Adriatic Sea have been performed annually by the research vessels "Dallaporta" and "Bios", equipped with SIMRAD echo-sounders (EK-500 and EK-60), and working with 38 kHz split-beam transducer (ES38B). Since the vessels have different characteristics and use different pelagic trawls for fish sampling, there is uncertainty regarding the comparability of the results obtained. In order to evaluate comparability of the results, a comparison between research vessels was performed. That included comparisons of vessels' noise, acoustic data collection, and fish samples composition and size structure analyses. The noise generated by both vessels was sufficiently low to allow a single fish detection up to 200 m depth. Acoustic data collected by the two vessels showed similar trends, no significant differences in average SA-values, and highly significant correlation between SA-values. Therefore, unbiased acoustic data collected by vessels could be combined in future stock assessments. Concerning collection of fish samples, anchovy resulted as the most abundant species in the samples collected by both vessels even if size compositions of anchovy were significantly different.*

**Key words:** Echo surveys, research vessels, acoustic properties, data acquisition, Adriatic Sea

## INTRODUCTION

The Adriatic Sea, particularly its northern part, is one of the most productive regions of the Mediterranean (SOURNIA, 1973). The continental shelf, which comprises the sea depth up to 200 m, includes 73.9% of the total Adriatic Sea surface (around 70000 km$^2$). Economically important biological resources for the pelagic fishery in the Adriatic Sea are small pelagic species, particularly anchovy (*Engraulis encrasicolus* Linnaeus, 1758), sardine (*Sardina pilchardus* Walbaum, 1792) and sprat (*Sprattus sprattus* Linnaeus, 1758) (TIČINA, 2003). These three species, together with Round sardinella (*Sardinella aurita* Valenciennes, 1874) represent almost 50% of the total annual landings in the Mediterranean (LLEONART & MAYNOU, 2003). These resources are shared by five nations (Italy, Croatia, Slovenia, Montenegro, Albania), support one of the largest fishing fleets in the Mediterranean, and are the main food source for large pelagic fish and three dolphin species. The bulk of the fishing fleet belongs to Italy and Croatia and operates in the northern and central parts of the Adriatic Sea (TIČINA & GIOVANARDI, 1997). The target species for Croatian fishing vessels is mostly sardine, while for Italian fishing vessels anchovy represents the main commercial interest (TIČINA *et al.*, 1999).

However, fisheries have to face the problem of the enormous spatial and temporal variability of these resources (AZZALI *et al.,* 2005, 2007; LEONORI *et al.*, 2009, 2011), mainly caused by the environmental factors (SINOVČIĆ & ALEGRIA-HERNANDEZ, 1997; TIČINA *et. al.*, 2000). Therefore it is vitally important to be acquainted with the annual availability of the pelagic biomass for each species. For that purpose, small pelagic surveys based on acoustics are being routinely performed in the European countries (LLEONART & MAYNOU, 2003). In the Adriatic, Italy has carried out acoustic surveys in the north western part of the Adriatic Sea since 1976, and in the central and south western part since 1987 (AZZALI *et al.*, 2002; LEONORI, 2007; LEONORI *et al.*, 2006a,b, LEONORI, 2011). Recently, the acoustically surveyed area in the Adriatic Sea has been extended to the Slovenian territorial waters and Albania and Montenegro continental shelf (LEONORI & DE FELICE, 2008). Acoustic surveys have been performed annually also in the northern and middle part of the Eastern Adriatic Sea by Croatian R/V "Bios" (TIČINA *et al.*, 2006). However, there was some uncertainty regarding the comparability of acoustic surveys results in the Adriatic Sea, mostly because of the insufficient information on the performances of different sampling equipment used by the two vessels. Eventually, an extended comparison exercise between two research vessels was performed in the Neretva channel on the southern coast of Croatia. Vessel comparisons included: 1) evaluation of the acoustical properties of each research vessel (i.e. vessels' noise) at speeds from 3.7 to 16.7 km/h (2 to 9 knots); 2) comparisons of collected acoustic data sets ($S_A$ values) and 3) comparison of fish samples collected by each vessel (i.e. species composition, mean size and size structure).

The aim of this paper is to describe possible differences in the obtained results when two or more different research vessels jointly conduct an acoustic survey, particularly if they use different sampling equipment. These findings could be useful indications for future acoustic surveys, particularly those jointly conducted aimed to assess abundance of small pelagic fish stocks shared between different countries.

## MATERIAL AND METHODS

### Study area

The study area is located in the Neretva Channel on the southern coast of Croatia, extending between 43°00'-43°10'N and 16°57'-17°25'E, with the depth range of 45-55 m (Fig. 1). In the environmental conditions determined by CTD measurements, the average sound speed in vertical direction within the acoustic field was 1519-1522 $ms^{-1}$ and the absorption coefficient (α) ranged between 8.13 and 8.82 dB/km.

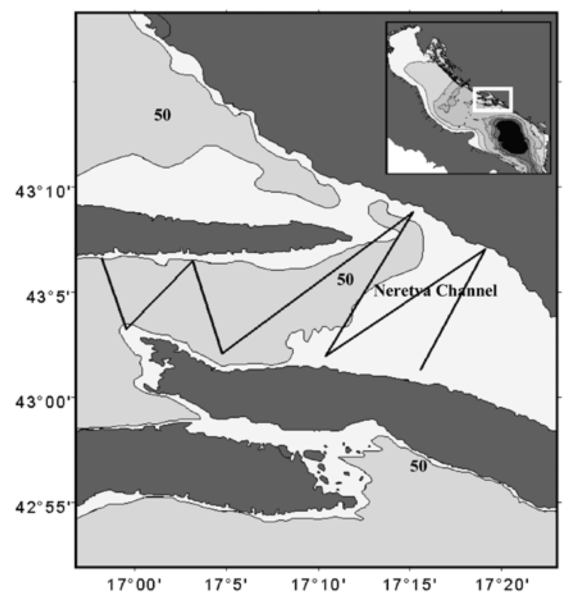


*Fig. 1. Map of the Neretva Channel showing location of the study area and acoustic transects*

### Noise from the vessels

The Italian R/V "Dallaporta" and Croatian R/V "Bios" have hulls made of steel and wood respectively and different technical characteristics (Table 1), possibly resulting in different levels of background noise.

Noise measurements were made on both research vessels at ship speeds ranging from 3.7 to 16.7 km/h (i.e. 2-9 knots), following the procedures described in SIMRAD manuals (SIMRAD, 1996). The relation between the maximum depth ($R_{max}$) for proper single fish echo detection and $S_i/N_i$ ratio was formulated in dB as follows:

*Table 1. Technical characteristics of research vessels*

| Characteristics | R/V "Dallaporta" | R/V "Bios" |
|---|---|---|
| Length (m) | 35.30 | 27.74 |
| Width (m) | 7.65 | 7.00 |
| Draught (m) | 3.40 | 2.80 |
| Gross tonnage (GRT) | 285 | 173 |
| Max speed (km/h) | 25.93 | 18.52 |
| (knots) | 14 | 10 |
| Survey speed (km/h) | 14.82-16.67 | 14.82-16.67 |
| (knots) | 8-9 | 8-9 |

$10Log(S_i/N_i) = (SL - 2(20Log(R_{max}) + (\alpha_{max}R_{max})) + TS_{min} - NL)$

where: NL is the measured Noise Level (dB re 1 μPa); SL is the Source Level (dB re 1 μPa at 1 m); $TS_{min}$ is the Target Strength of a proper single fish (10 Log $(\sigma_{min}/4\pi(r_0)^2$, $r_0 = 1$ m); $\alpha_{max}$ is the sound absorption coefficient ($\alpha_{max} = 8.82$ dB/km at 38 kHz).

**Acoustic data ($S_A$) collection**

The acoustic systems installed on R/V "Dallaporta" and R/V "Bios" were SIMRAD EK500 and SIMRAD EK60 respectively. Both systems operated with the same transducer model (SIMRAD ES38B split beam transducer), used the same transmitting power (2000 W), pulse length 1.024 ms and thresholds of -70 dB for volume backscattering strength ($S_v$) and for single echo detections (TS). Echo-integrator values $S_A$ ($m^2/nmi^2$) were collected from 7 m depth up to bottom. The bottom offset was set at 0.5 m.

Before the vessels' comparison, the acoustic equipment on both vessels was accurately calibrated using the standard target (copper sphere, 60 mm in diameter, density 8.945 $kg/m^3$, TS = -33.6 dB) following the procedures described by SIMRAD (SIMRAD, 1996; FOOTE *et al.,* 1987).

Acoustic data were collected during four identical mini-surveys with 7 zigzag transects each (Fig. 1), twice during daytime and twice during the night. Total length of all transects in each mini-survey was 83.34 km (i.e. 45 nautical miles (nmi)). Echo sounders received the vessel navigation data from standard GPS. The two vessels sailed in formation, at a speed of approximately 15.7 km/h (i.e. 8.5 knots), with one in the lead and other approximately 340 m (0.2 nmi) astern and far enough to the side to be clear of the leader's wake (JOHANNENSSON & MITSON, 1983; SIMMONDS & MACLENNAN, 2005). In the first two mini-surveys (day and night) R/V "Bios" took the lead position (Fig. 2), and in the last two R/V "Dallaporta" did. The acoustic data collected were averaged within an elementary distance sampling unit (EDSU) of 1 nmi to give


*Fig. 2. R/V "Dallaporta" as seen from the R/V "Bios" during the two vessels comparison*

one sample. Acoustic data were recorded in the form of colour echogram printouts, as well as raw data files on hard disk and DVD. The files contained echo integration results and TS distributions for each EDSU.

### Fish sampling

In order to identify the species composition and size distributions of different acoustic targets (i.e. fish species), research vessels were equipped with sampling pelagic trawls with doors, similar in design but different in size. Nominal mesh sizes in the cod-ends were 18 mm and 16 mm in trawls used by R/V "Dallaporta" and R/V "Bios" respectively. The pelagic trawl on R/V "Dallaporta" had a mouth opening of 6-8 m in height and 12-13 m in width corresponding to the net mouth area of approximately 85-90 $m^2$. The pelagic trawl on R/V "Bios" had a mouth opening of 3-4 m in height and 8 m in width corresponding to the net mouth area of approximately 25-30 $m^2$. For monitoring the net position in the water column and the vertical opening of the net mouth the SIMRAD ITI system was used in R/V "Dallaporta" and NetMind system in R/V "Bios". In both vessels fishing speed was maintained at approximately 7.4 km/h (i.e. 4 knots). The standard haul duration was 30 minutes for both vessels.

During each mini-survey two pair-wise hauls were performed by the two vessels. A total of eight hauls were carried out by each vessel, but two of them (hauls no. 4 and 7) were unsuccessful due to technical difficulties, and therefore not considered in analyses. The position of the vessels and the position of the trawls within water column were kept as similar as possible during fish sampling operations. Fish samples collected were analysed on board immediately after sampling. Total weight of each species was recorded. The most abundant target species (anchovy) was used for comparison of its size structures. Total length (TL) of individuals was measured to the nearest 0.5 cm below, and specimens within each length class were weighed with an accuracy of ±1 g. In very abundant catches, subsamples of anchovy were taken for the length frequency distribution.

### Data analysis

Noise measurements on both research vessels were compared with the echo level of a single fish with target strength of –55 dB at 200 m depth, as well as with maximum noise level allowed to detect that fish at a given depth (10Log(Si/Ni) > 10 dB) .

Differences in acoustic data collected by the two vessels during the four mini-surveys were analysed independently for each mini-survey, using the two-tailed Student's t-test. The linear regression analysis together with ANOVA was applied to all comparable data collected during the four surveys to test the correlation of data collected by the two research vessels (SOKAL & ROHFL, 1995). Differences between $S_A$ data collected by each vessel among the four mini-surveys, as well as differences between day and night surveys were tested by the Kruskal-Wallis test.

Differences in species composition of the fish samples collected for all the pair-wise hauls by the two vessels were analysed using the Wilcoxon test, while length frequency distributions obtained by the different vessels were compared using the two-tailed paired t-test (SOKAL & ROHFL, 1995).

## RESULTS

### Comparisons of the research vessels' noise

Source Level (SL) values of both vessels calculated from the respective echo-sounders calibrations were almost identical (difference <0.2%, Table 2). The noise level (NL) generated by R/V "Dallaporta" was 3.6 dB re 1 μPa higher than NL generated by R/V "Bios", measured at a vessel speed of 16.7 km/h (9 knots). In Table 2 are also reported the NL values and the Signal/

*Table 2. Source Levels (SL), Noise Levels (NL) and Signal/ Noise ratio for a single fish (TS = –55 dB) at 200 m depth obtained by two research vessels (vessels speed = 16.7 km/h (9 knots); α = 8.82 dB km-1)*

| Research vessel | "Bios" | "Dallaporta" |
|---|---|---|
| SL (dB re 1μPa at 1m) | 227.94 | 228.36 |
| NL (dB re 1μPa) | 62.30 | 65.90 |
| Signal/Noise (dB) | 15.01 | 11.90 |

Noise ratios for a single fish with TS = -55 dB (i.e. the TS of an anchovy of around 10 cm) at a range of 200 m, taking into account the maximum absorption coefficient (α) value of 8.82 dB/km measured during this study. The results show that on both research vessels the signal-to-noise ratio is >10 dB (Table 2). This means that both research vessels are fully capable of detecting echo-signals of single fish under examination up to 200 m.

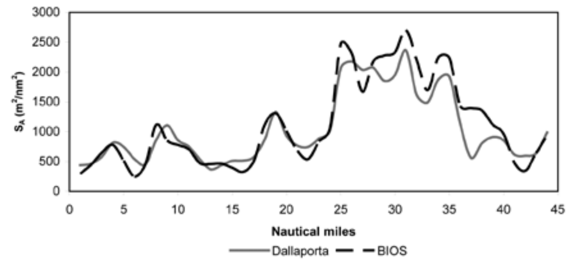


*Fig. 3. Comparison of SA-values measured by the two research vessels during the first mini-survey (night) in the Neretva Channel*

### Comparison of the acoustic data ($S_A$)

The trends of $S_A$-values collected by research vessels "Bios" and "Dallaporta" along the transect lines in each survey were compared for the corresponding nautical miles. The trends of volume backscattering area data in each survey were quite similar, as illustrated for the first mini-survey on Figure 3. The average $S_A$-values measured by R/V "Bios" were 7.3-13.1% higher than those measured by R/V "Dallaporta", but these differences, analysed for each pair of four mini-surveys, were not significant (Table 3). The overall average $S_A$-values from the four surveys were very close: 1020.58 $m^2/nmi^2$ and 1123.85 $m^2/nmi^2$ for R/V "Dallaporta" and R/V "Bios", respectively. This difference was not significant (t test, P >0.05).

The results of ANOVA (F = 168.698, P < 0.01) confirmed the existence of the highly significant linear relation between the two $S_A$-values data sets. Linear regression analysis (Fig. 4) showed that correlation of acoustic data collected by the two research vessels can be described by the following equation:

$S_A$(Bios) = 1.0646 * $S_A$(Dallaporta) + 37.339 ($r^2$ = 0.7526).

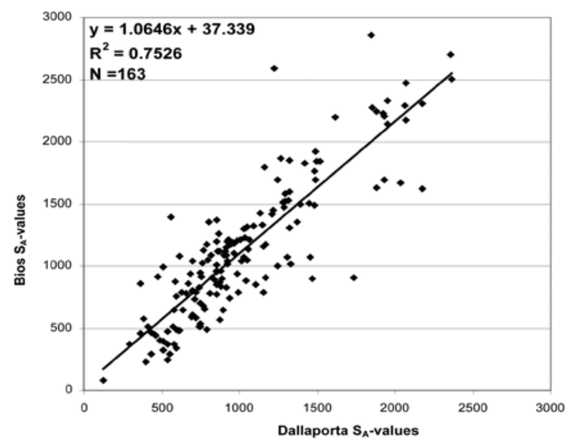


*Fig. 4. Linear regression of SA-values measured by the two research vessels*

For each vessel, $S_A$-values averaged along entire transect lines presented non-significant variations among the four mini-surveys, and between day and night surveys (Kruskal-Wallis tests: P > 0.05).

### Comparison of the fish sampling

The species compositions of the fish samples collected by the two research vessels were not

*Table 3. Comparisons of SA-values measured by two research vessels during four mini-surveys in the Neretva Channel*

| | Survey 1 (night) | | Survey 2 (day) | | Survey 3 (night) | | Survey 4 (day) | |
|---|---|---|---|---|---|---|---|---|
| | "Dallaporta" | "Bios" | "Dallaporta" | "Bios" | "Dallaporta" | "Bios" | "Dallaporta" | "Bios" |
| N | 44 | | 35 | | 45 | | 39 | |
| Sum | 45567 | 48899 | 35487 | 39752 | 46838 | 52985 | 38467 | 41556 |
| Avg | 1035.6 | 1111.3 | 1013.9 | 1135.8 | 1040.8 | 1177.4 | 986.3 | 1065.5 |
| SD | 580.35 | 721.82 | 378.21 | 450.96 | 460.32 | 602.13 | 376.49 | 392.63 |
| $P_{(t\text{-}test)}$ | 0.589 | | 0.225 | | 0.230 | | 0.336 | |

*Table 4. Composition of the total catches from the two research vessels*

| Research vessel | | | Target species | | Other pelagic species | Pelagic species as a whole | Bottom species | Total catch (g) | Filtrated volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Anchovy | Sardine | | | | | |
| Dallaporta (6 hauls) | Total weight | g | 28777 | 2282 | 3037 | 34097 | 2606 | 36722 | 1851400 |
| | | % | 78% | 6% | 8% | 93% | 7% | | |
| | No. | | 2033 | 119 | 42 | 2194 | | | |
| | Length (cm) | Mean | 12.88 | 13.51 | 16.29 | 12.98 | Not measured | | |
| | | SD | 0.99 | 0.37 | 1.79 | 0.87 | | | |
| BIOS (6 hauls) | Total weight | g | 2090 | 97 | 4299 | 6486 | 5947 | 12433 | 619198 |
| | | % | 17% | 1% | 35% | 52% | 48% | | |
| | No. | | 194 | 6 | 77 | 2.77 | | | |
| | Length (cm) | Mean | 12.19 | 12.92 | 18.06 | 13.84 | Not measured | | |
| | | SD | 0.85 | 0.87 | 4.89 | 3.71 | | | |

significantly different (Wilcoxon test; P >0.05) although species other than anchovy and sardine predominated (82.40% of the total catch) in the R/V "Bios" catch, while anchovy and sardine constituted 84.58% of the total R/V "Dallaporta" catch as shown in Table 4. However, the ratios between target species (i.e. anchovy and sardine) within samples collected by both vessels were similar. In samples collected by R/V "Bios" and R/V "Dallaporta" anchovies made up 95.5% and 92.7% respectively, while sardines made up 4.5% and 7.3% of the target species respectively.

In R/V "Dallaporta" catches anchovy lengths ranged over 10.5-15.5 cm, with mean length of 12.9 cm (SD = 0.99; n = 2033). In R/V "Bios" catches anchovy lengths ranged over 10.5-15.0 cm, with mean length of 12.2 cm (SD = 0.85; n = 194). The anchovy length frequency distributions found by R/V "Dallaporta" and R/V "Bios" (Fig. 5), as well as the mean length of specimens differed significantly (t-test, p < 0.01).

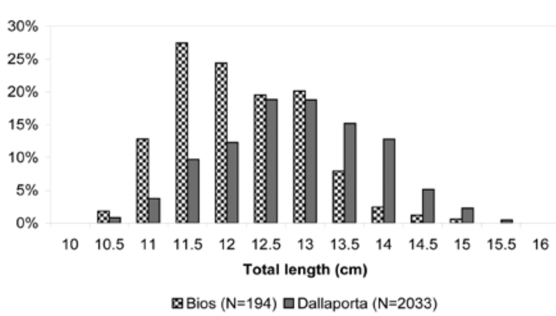


*Fig. 5. Length frequency distribution of anchovies caught by the two research vessels*

## DISCUSSION

It is known that the level of background noise generated by a vessel could restrict the detection of the fish echo. The efficiency of fish detection is determined by the minimal intensity of their echo-signals required for their registration by the receiver against background noise (KALIKHMAN & YUDANOV, 2006). For quantitative acoustic measurements, a Signal-to-Noise ratio >10 dB is necessary (JOHANNENSSON & MITSON, 1983), so that single fish can be detected up to the maximum depth (around 200 m for small pelagic fish). Signal-to-Noise ratios obtained by noise measurements made on both research vessels fulfilled this requirement, indicating that noises generated by R/V "Bios" and R/V "Dallaporta" do not represent an obstacle for acoustic surveys of small pelagic fish up to

200 m depth. Despite the different engines and hull constructions (wood vs steel), we concluded that both research vessels were fully capable of detecting all echo-signals of the target species of small pelagic fish up to 200 m depth at a cruising speed of 16.7 km/h (9 knots).

The comparison of the acoustic data of the two vessels was remarkably consistent. The stability of $S_A$ trends and mean $S_A$ values indicates that the surveying performances of the two research vessels are stable and that the acoustic data are insensitive to night or day sampling. High correlation determined between $S_A$-values recorded by the two research vessels in all surveys and the slope of the regression line close to unity suggest that both vessels collect unbiased acoustic data, and that the differences in $S_A$ data, which could be caused by the slight shifting between the tracks of the two vessels, can be considered insignificant. Regression equation obtained in comparisons between two vessels can be used for full harmonization of acoustic data sets collected by these vessels, eventually improving estimates obtained in small pelagic stocks assessments in the Adriatic basin.

Therefore, $S_A$ data collected by the two vessels could be considered unbiased, eventually comparable and the entire geographic area covered by these vessels can be combined with relatively high precision to produce one common spatial distribution map extending from the Croatian to the Italian coast in future stock assessments.

Concerning fish sampling, the composition of the total fish samples collected by the two different trawls differed greatly even if in haul by haul comparisons the species composition was not significant different between the two vessels. This is probably due to the between-haul variation (FRYER, 1991).

The comparison of size structure of fish samples indicated that the larger trawl caught a higher proportion of larger specimens. The significant differences in mean size and length frequency distributions of anchovy sampled by the two research vessels could be related to the different catch volumes, but also to the higher amount of larger individuals in the R/V "Dallaporta" catches. This difference might result from the avoidance ability of the largest and fastest specimens. The avoidance effect depends critically on swimming speed related to net mouth dimensions (BETHKE *et al.*, 1999). In addition, the larger amount of smaller specimens in the R/V "Bios" trawl could be related to a different selectivity pattern due to different mesh sizes in the cod-ends. In this case, these differences in mean size and length frequency distributions of anchovy samples eventually cause differences in biomass estimates between different length classes. O'DONELL *et al.* (2009) also reported large differences in amounts of fish samples collected, size structure and mean length of fish between two vessels, even when they used the same fish sampling gear (pelagic trawl), fishing on the same depth layer and targeting the same fish concentrations.

In conclusion, it is still not quite clear if these differences in our case could be related entirely to the larger trawl of R/V "Dallaporta" and slightly different mesh size in the cod-ends (i.e. systematic error), or if they should be considered as a normal consequence of random sampling (i.e. random error). In the authors' opinion, more research effort is needed to properly answer this question. However, with the goal to overcome that uncertainty, and reduce as much as possible sources of systematic fish sampling errors in acoustic assessment, standardization of fish sampling equipment between different research vessels conducting joint acoustic survey is highly recommended in order to increase the accuracy of the final results.

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# Poredbena analiza značajki dvaju istraživačkih brodova za obavljanje eho-monitoringa sitne plave ribe

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## SAŽETAK

Eho-monitoring u Jadranskome moru provodi se jednom godišnje korištenjem istraživačkih brodova “Dallaporta” i “Bios”, opremljenih s ehosonderima SIMRAD (EK-500 i EK-60), te pretvaračima podijeljenog snopa radnih frekvencija od 38 kHz (ES38B). Budući da ovi istraživački brodovi imaju različite značajke, a koriste i različite pelagijske koće za uzorkovanje sitne plave ribe, postoje sumnje glede usporedivosti prikupljenih podataka. S ciljem procjene usporedivosti prikupljenih podataka, napravljena je usporedba u prikupljanju podataka ovim istraživačkim brodovima. Uspoređena je buka pojedinih brodova, prikupljanje akustičkih podataka, te usporedbe prikupljenih uzoraka riba s obzirom na sastav i strukturu uzoraka. Utvrđeno je da buka koju proizvode oba broda je dovoljno niska da dozvoljava detekciju pojedinačnih riba do dubine od 200 m. Akustički podaci prikupljeni dvama istraživačim brodovima pokazuju slične trendove, bez značajnih razlika u srednjim $S_A$-vrijednostima i s vrlo značajnom povezanošću među njima. Potvrđeno je da se budućim procjenama ribljih naselja nepristrani akustički podaci ovih brodova mogu međusobno nadopunjavati. Glede prikupljanja uzoraka riba, došlo se do spoznaje da je inćun bio najzastupljenija vrsta u uzorcima koje su sakupila oba istraživačka broda iako je njihova veličinska struktura bila značajno različita.

**Ključne riječi:** eho-monitoring, istraživački brodovi, akustičke osobitosti, prikupljanje podataka, Jadransko more