ICES CM 2008/Theme session (I). Fishing Capacity, effort and fishing mortality; The understanding of fishery dynamics and their links to management

Estimation of pelagic trawl efficiency in a combined acoustic-trawl survey, with reference to demersal fish spatial distribution.

M. Doray, S. Mahévas, V.M. Trenkel

Few analyses have been performed to estimate the efficiency of trawls targeting demersal fish using the ratio of catches and acoustic densities. In the summer of 2006, acoustic and fishing data have been collected simultaneously during three days by three fishing vessels equipped with identical semi-pelagic trawls during a scientific survey (CHAPAUV'06) in the Bay of Biscay. These data have been used to compute diel trawl efficiency estimates for selected demersal species and to relate them to the fish assemblage spatial structure. Acoustic back-scattering densities expressed as Nautical Areal Scattering Coefficients (NASC) recorded in the trawled layer were compared to Equivalent NASC (ENASC) calculated from the species composition in the trawl, their length structure and available target strength-length relationships. Trawl efficiency estimates were computed using log-linear or generalised linear models, as the slope, Q, of the relationship: ENASC=Q*NASC^b, for hake-dominated trawls and for the whole demersal community at day and night, and for horse mackerel-dominated trawls at day. No significant horizontal spatial autocorrelation was found in the acoustic data at the haul scale (~4 km).

Keywords: trawl efficiency, availability, catchability, vulnerability, spatial distribution, acoustics, pelagic trawl, hake, Bay of Biscay, GLM.

Contact author:

M. Doray, Département EMH, Ifremer-Nantes, Rue de l'Ile d'Yeu, BP 21105, 44300 Nantes Cedex 3 France. tel: +33 (0)2 40 37 41 65 - fax : +33 (0)2 40 37 40 75, e-mail: mathieu.doray@ifremer.fr

Introduction

Trawl catchability (q) is the constant of proportionality between trawl catch-per-unit-effort and the true population density (Hilborn & Walters, 1992). Two biological processes underlie trawl catches: the abundance and spatial distribution of fish populations and capture efficiency. The first component determines the number of fish in the trawl path (swept area) and the second describes how many of these will end up in the codend (Trenkel & Skaug, 2005). For a given population, trawl catchability is hence commonly broken down into horizontal and vertical availability and gear efficiency (Godø, 1994). Gear efficiency is determined by gear technology (net selectivity, gear rigging, fishermen skills) and fish reactions to the approaching gear (herding, escapement). Horizontal availability is the probability that an individual is found in the fishing area, whereas vertical availability is the probability that an individual is at the right distance from the bottom in order to be caught by the particular fishing gear (Trenkel *et al.*, 2004).

Disentangling the effects of availability and gear efficiency on catch data is important to properly analyse trawl survey data, as well as to refine the estimation of trawl catchability in stock assessment models. Trenkel and Skaug (2005) propose a random effects model explicitly accounting for the effects of fish spatial distribution and gear efficiency on trawl catches of demersal fish. One can also try to compute direct trawl efficiency estimates, using e.g. gear comparison experiments where gear efficiency is estimated as the quotient of fish density (catch per area swept) from the fishing gear to density estimates from an other investigative tool believed to be completely efficient, such as visual or acoustic transects (Somerton *et al.*, 1999). In many cases no observation method will provide absolute estimates, hence many trawl efficiency estimates are relative (e.g. Trenkel et al., 2004). Few analyses have been performed to estimate trawl efficiency using the ratio of trawl catches and acoustic densities (O'Driscoll *et al.*, 2002). This might be because the relationship between acoustic and bottom trawl data can be rather vague, as demonstrated for example for the North Sea demersal fish community (Mackinson *et al.*, 2005). However, Krieger *et al.* (2001) found a clear relationship between the two data types for rockfish and O’Driscoll *et al.* (2002) for capelin in the case of a midwater but not a bottom trawl (Krieger *et al.*, 2001). For cod and haddock, the relationship varied between size classes, on a daily and seasonal basis and with the assumed fishing height of the bottom trawl (Hjellvik *et al.*, 2003).

Here, we analyse the data obtained during a combined acoustic-trawl survey to compute direct estimates of trawl efficiency for an assemblage of demersal fishes exploited by semi-pelagic trawlers. Acoustic and fishing data have been collected simultaneously during three days by three fishing vessels equipped with identical semi-pelagic trawls during a scientific survey (CHAPAUV'06) in the Bay of Biscay. These data have been used to compute direct diel trawl efficiency estimates for a mixture of demersal species dominated by hake (*Merlucius merluccius*), blue whiting (*Micromesistius poutassou*) and horse mackerel *(Trachurus trachurus)*.

For survey catches with no spatial targeting, if the spatial fish distribution is random, this knowledge can be used to extract directly estimates of gear efficiency from the distribution of numbers per tow (Trenkel & Skaug, 2005). Furthermore, it has been demonstrated that fish spatial distribution impacts trawl efficiency by commercial fishing fleets (through horizontal availability), if fishing effort is targeted rather than randomly distributed in space (e.g. Ellis and You-Gan, 2007). Using the continuous acoustic observations we study the fish assemblage spatial structure at both the trawl haul scale (km) and the survey scale (tens of km). The current analysis allows to: i) validate the basic assumption of randomness of the hake spatial distribution in Trenkel and Skaug (2005)'s model, and ii) to investigate the influence of fish spatial structure on trawl efficiency and fish availability.

Material and Methods

Data

In July 2006, acoustic and catch data were collected simultaneously in the Bay of Biscay during three days by three twenty meters long chartered fishing vessels (F/V "Davidson", F/V "Hebeilan" and F/V "Océanie") equipped with identical semi-pelagic trawls (4 doors, headline: 54 m, foot rope: 50 m). The survey was conducted in a 30 x 12 nautical miles flat muddy area of constant bathymetry (100 m depth), known to be a major hake fishing ground A total of 84 trawl hauls were performed during day and night time at 28 trawl stations. A subset of 72 hauls for which acoustic recordings were available were selected for further analysis. These hauls were performed at 24 trawl stations (12 daytime and 12 night-time stations), following a pseudo-parallel survey design (Fig. 1). The 20 m vertical and 40 m horizontal opening trawl was set at about 0.5 m above the bottom for 30 minutes, every hour, between midnight and 8 pm. Catches were sorted and all or a subsample was measured. One vessel (F/V Davidson) was equipped with a portable Simrad ER60 echosounder connected to a 11° beam angle, spherical split-beam transducer, operating vertically at the 70 kHz frequency. The transducer was operated at a 0.512 ms pulse length in a paravane towed between 3 and 5 knots at about 2 m below the surface on the port side of the vessel during and between fishing stations. *In situ* on-axis calibration of the echosounder was performed before the cruise using standard methodology (Foote, 1982). Acoustic surveys were replayed with the Movies+ software (Weill *et al.*, 1993) and archived in the international hydro-acoustic data format (HAC) (Simard *et al.*, 1997) at a -80 dB threshold.

Acoustic backscatters with volume backscattering coefficients (s_V) larger than –60 dB were allocated to fish. They were echo-integrated with Movies+ software within 80 bottom depth layers of 0.5 m height, from 0.5 to and 40.5 m above the bottom, and within 36 2 m wide depth layers from 40.5 m to the sea surface. The size of horizontal elementary sampling units (ESUs) was 20 ping, corresponding to 40 m long ESUs at a mean speed of 4 knots. The semi-pelagic trawl zone was considered to be the volume from 0.5 to 40 m off the bottom. The trawl vertical opening is only 20 m, but the effective fishing height of the trawl is actually higher than the actual height of the trawl opening, as fish swim down into the trawl in response to vessel noise (Hjellvik *et al.*, 2003). Total Nautical Area Scattering Coefficient (NASC) values (MacLennan *et al.*, 2002), $NASC_{tot}(t)$, corresponding to each trawl haul were then calculated as the average NASC value per meter computed from 0.5 to 40.5 m above the sea floor in each ESU.

Estimated Nautical Area Scattering Coefficient calculation

Estimated Nautical Area Scattering Coefficients (Simmonds and MacLennan, 2005), $ENASC_s(t,v)$, were computed for each of the main species s, sampled in station t on vessel v as (Mackinson *et al.*, 2005):

$$ENASC_s(t,v)=\frac{4\pi\times\hat{N}_s(t,v)\times\sigma_{bs-s}}{A}, \tag{1}$$

where: A is the area swept during a trawl haul (in squared nautical miles), $\hat{N}_s$ is the (estimated) catch in numbers of species s in station t of vessel v, and σ_{bs-s} is the theoretical backscattering cross-section (MacLennan *et al.*, 2002) of species s. A was estimated based on trawl geometry data recorded on vessels Hebeilan and Océanie, using Scanmar systems. σ_{bs-s} values were computed as $\sigma_{bs-s}=10^{TS/10}$, where TS are theoretical target strength values derived from the relationships presented in Table 1.

$ENASC_s(t,v)$ of all species were summed per haul to compute total ENASC values, $ENASC_{tot}(t,v)$, for each trawl station t performed on vessel v.

Trawl efficiency estimates

The relationship between catch, C, and true abundance, N, can be expressed as:

$$C=EqN^b, \tag{2}$$

where q is the catachbility, E is the (nominal) fishing effort represented in our case by trawl duration and b is an abundance exponent. If b is taken to be 1, one gets the linear relationship between catches and abundance classically used in stock assessment. Conversely, b values lesser than 1 allow for the accommodation of some non linearity in the relationship between catches and abundance.

We assume that the $NASC_{tot}(t)$ value recorded onboard F/V Davidson during station t is a reasonable estimate of the true abundance of demersal fish encountered along the haul track. So, replacing N in eq 2 by $NASCtot(t)$, we obtain the relationship:

$$ENASCtot(t,v) = E(t,v)\ q(t,v)\ NASCtot^b(t) = Q(t,v)\ NASCtot^b\ (t), \tag{3}$$

where *Q(t,v)* is the trawl efficiency, defined as the proportion of animals within the swept volume which are captured by the trawl (Somerton *et al.*, 1999). Equation (3) writes in log scale:

$$ENASC_{tot}(t,v) = Q(t,v) NASC_{tot}^{b}(t) \Leftrightarrow \log\left(ENASC_{tot}(t,v)\right) = b\log\left(NASC_{tot}(t,v)\right) + \log\left(Q(t,v)\right) \quad (4)$$

Q(t,v) and *b* were estimated by fitting generalised linear or log-linear models to ENASC values per vessel. The choice of residuals distribution, link function and the form of the ENACS transformation was made to ensure no violation of GLM assumptions (homoscedasticity, explained deviance). Due to diel variations of the *ENASC/NASC* ratios, daytime and night-time hauls were analysed separately. Diel trawl efficiency coefficients were then estimated for subsets of trawl stations where the proportion in weight of one species was higher than 50% in at least one of the three parallel trawl hauls. Global diel trawl efficiency coefficients where also computed over all day and night stations, as an estimate of the main trawl efficiency of the demersal fish community in the area. In the case of daytime or night-time hake-dominated hauls and overall night-time hauls, the best-fit model was a generalised linear model assuming a gamma distribution for residuals and a log link function:

$$\log\left(E\left[ENASC_{tot}(t,v)\right]\right) = b \times \log\left(NASC_{tot}(t,v)\right) + \log\left(Q\right) + \varepsilon \qquad \varepsilon \sim Gamma \quad (5)$$

In the case of daytime horse-mackerel dominated hauls and overall daytime hauls, the best-fit model was a log-linear model assuming a Gaussian distribution for residuals:

$$\log\left(ENASC_{tot}(t,v)\right) = b \times \log\left(NASC_{tot}(t,v)\right) + \log\left(Q\right) + \varepsilon \qquad \varepsilon \sim Normal \quad (6)$$

Systematic vessel and station effects were tested, which would mean that: $Q(t,v) = Q_1(t)\ Q_2(v)$.

Spatial structure

Empirical variograms of total NASC values in the trawled layer, aggregated into 0.1 nautical miles long ESUs, where computed for each hake-dominated station. These empirical variograms were averaged for day and night time stations within each distance class. Resulting mean daytime and night-time empirical variograms were analysed to assess the spatial structure of the hake-dominated fish assemblage.

Results

Species composition of trawl hauls

Overall trawl catches were dominated in weight by hake (38%), horse mackerel (33%) and blue whiting (23%). Hake catches were fairly constant throughout the survey (Figure 2). However, dramatic diel variations were observed in the size distribution of this species. Hake mean size was about 30 cm during daytime and a second length mode appeared at night, with catches of smaller fish of mean length 20 cm. High horse mackerel catches were essentially recorded during day 2 (Figure 2), at the same time large dense schools were detected by acoustics (results not shown).

The hake proportion in weight in the catches was higher than 50% in at least one trawl haul for 5 trawl stations (14 hauls) during daytime and 6 stations (18 hauls) during night-time. The mean species compositions in weight of daytime/night-time hake dominated hauls were: hake, day: 47%; hake, night: 72%; horse mackerel, day: 27%; horse mackerel, night: 6%; blue whiting, day: 18%; blue whiting, night: 16%. The horse mackerel proportion in weight in catches was higher than 50% in at least one trawl haul for 8 trawl stations (24 hauls) during daytime. The mean species composition of horse mackerel dominated hauls was: hake: 18%, horse mackerel: 69% and blue whiting: 9%.

Hake trawl efficiency estimates

The average daytime hake trawl efficiency coefficient was 0.008 (SD 0.03, 50% deviance explained; Figure 3, Table 2). The estimated exponent b was 0.91 (SD 0.28) , which means it was not significantly different from 1(Table 2).

The estimated average night-time hake trawl efficiency was 0.18 (SD 0.045, 23% deviance explained; Figure 4, Table 2). The exponent estimate was 0.31 (SD 0.14) (Table 2), thus b was significantly different from 1,.

Horse mackerel trawl efficiency estimate

The average daytime estimate of horse mackerel trawl efficiency was 0.003 (SD 0.019, 42% variance explained; Figure 5, Table 2). The exponent estimate was 1.3 (SD 0.28) (Table 2) and therefore not significantly different from 1.

Global trawl efficiency estimates

All daytime and night-time trawl hauls, whatever the species composition, were considered in this analysis. The average daytime trawl efficiency estimate of the demersal community for semi-pelagic trawls was 0.002 (SD 0.006, 50% variance explained; Table 2) with an exponent of 1.3 (SD 0.21) (Table 2) which was not significantly different from 1. Trawl efficiency did not vary systematically between fishing vessels. The average night-time trawl efficiency estimate of the demersal community for semi-pelagic trawls was 0.17 (SD 0.06, 25% deviance explained; Table 2) with an exponent of 0.33 (SD 0. 1) (Table 2) which is significantly different from 1. Again trawl efficiency did not vary systematically between fishing vessels.

Spatial structure of hake-dominated fish assemblage

Day and night time mean empirical variograms did not reveal any spatial structure in the hake acoustic densities at the scale of a trawl haul of length 4 km (Figure 6).

Discussion

The first question that arises when comparing acoustical densities and trawl catches of demersal fishes is whether the trawls and the echosounder measure the same thing. In our case, the footrope of the semi-pelagic net worked 0.5 m above the bottom, i.e. above the acoustic dead zone extending 0.5 m above seabed at a 0.512 ms pulse length. A 0.5 m bottom offset was used for the echo-integration of fish backscatters to exclude echoes from the dead zone and ensure that fish acoustic densities and catches were measured in the same depth range. However, besides classical avoidance reactions accounted for by the estimated trawl efficiency coefficients (i.e. swimming down the footrope or up the headrope), some demersal fish located under the footrope might have reacted to the disturbance caused by the trawl by swimming up into the net. The vertical distribution of *M. merluccius* being poorly documented, one cannot rule out the possibility that *ENASC* values might have been biased upward, due to such vertical avoidance reactions. However a combined acoustic/trawl study conducted in Namibia showed that *Merluccius paradoxus* of size similar to those of *M. merluccius* caught during daytime in our study, were generally more abundant 5-50 m off the bottom, whereas larger *Merluccius capensis* dominated just over the seabed (Huse *et al.*, 1998). If such a diurnal size at-depth distribution also prevails for *M. merluccius*, the abundance of 30 cm hake located within the 0.5 m unsampled layer was low during daytime. In this case, one could assume that the bias induced in *ENASC* values by the vertical avoidance of this fraction of unsampled hake into the trawl was small.

The survey was conducted in a supposedly homogeneous area populated by a demersal fish community dominated by hake. The trawl haul composition was however relatively variable and diverse. This is seemingly due to mobile schools of species such as horse mackerel or blue whiting moving throughout the area. As the accurate allocation of the fish acoustic energy to each of the species found in the catches was not possible, our trawl efficiency estimates then represent the vulnerability of a mixture of demersal species towards a semi-pelagic trawl. Conducting a large number of hauls is hence required to maximize the odds of getting a sufficient number of haul catches dominated by a particular species, to allow for the computation of species specific trawl efficiency estimates.

Hake was caught in rather stable proportions during all hauls and appeared to be widely and randomly distributed in the area. This is corroborated by small-scale video observations conducted in an area close to the current study (Trenkel *et al.*, 2007). The spatial distribution and trawl efficiency coefficient of this species was then reasonably well assessed with our survey design. Conversely, horse mackerel and, to a lesser extent, blue whiting, formed discrete, relatively dense schools. The mean acoustic beam diameter over trawl horizontal opening ratio being 0.4, the probability for horse mackerel and blue whiting schools to be insonified by the acoustic beam was lower than the probability to be caught by the trawl. Horse mackerel and hake patchy distribution at the very small scale hence possibly caused a positive bias in *ENASC* estimates compared to *NASC* values recorded for the same haul, leading to a positive biais in trawl efficiency estimates.

Night-time exponents and trawl efficiencies dramatically differed from these estimated for daytime. Observed discrepancies in trawl efficiency are probably due to the presence within the trawl zone during night-time of smaller hakes (20 cm mean length) not observed in catches during daytime. Besides differences in avoidance reactions due to different light levels or fish diel activity (accounted for by the trawl efficiency coefficient), estimates of $b<1$ in fact represents a net reduction of the amount of hake biomass available to the trawl, which could be explained by a higher trawl selectivity for the smaller hake present at that time.

This study demonstrated that catch efficiency estimates of semi-pelagic trawls targeting demersal species can be computed at a coarse scale, by combining fishing and acoustic data, providing that these species are distributed slightly above the bottom. Estimated trawl efficiency estimates varied between species and diel periods and one can assume that they would potentially change from one fishing ground or season to another. Such gear efficiency coefficients could be routinely computed based on trawl survey data or catches and acoustic data recorded onboard commercial vessels equipped with calibrated echosounders and automatic data loggers. This would provide useful insights into the larger scale variability of the catching process, as well as catchability estimates to be used in stock assessment in the absence of long time series of fisheries statistics (Somerton *et al.*, 1999).

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Tables

Table 1. Species code, reference species, frequencies and b20 values used in TS = 20log(L)+b20 to compute theoretical TS of sampled species, as a function of fish length L.

Species	Scientific name	Reference species	b_{20}	Frequency (kHz)	Reference
Hake	*Merluccius merluccius*	*Merlucius gayi*	-68.5	38	(Lillo *et al.*, 1996)
Blue whiting	*Micromesistius poutassou*	*Micromesistius poutassou*	-71.9	29	(Robinson, 1982)
Sardine	*Sardina pilchardus*	*physostome*	-71.9	38	(Foote, 1987)
Horse mackerel	*Trachurus trachurus*	*Trachurus trachurus capensis*	-66.8	38	(Barange *et al.*, 1996)
Mackerel	*Scomber scombrus*	*Scomber scombrus*	-84.9	38	(Edwards *et al.*, 1984)

Table 2. Estimates of trawl efficiency coefficients (q) and exponents (b) from the models relating Equivalent NASC to NASC, along with estimation errors (q SD and b SD).

Species	**Error distribution**	**Diel period**	**q estimate**	**q SD**	**b estimate**	**b SD**
Merluccius merluccius	Gamma	Day	0.008	0.026	0.91	0.28
Merluccius merluccius	Gamma	Night	0.180	0.045	0.31	0.14
Trachurus trachurus	Normal	Day	0.003	0.019	1.3	0.29
All species	Normal	Day	0.002	0.006	1	0.21
All species	Gamma	Night	0.170	0.065	0.33	0.1

Figure captions

Figure 1. a) General geographical location of the study area (rectangle); b) Magnification of the study area with log transformed fish Nautical Area Scattering Coefficients per successive diel periods during CHAPAUV cruise. Successive day/night periods are represented with different colors.

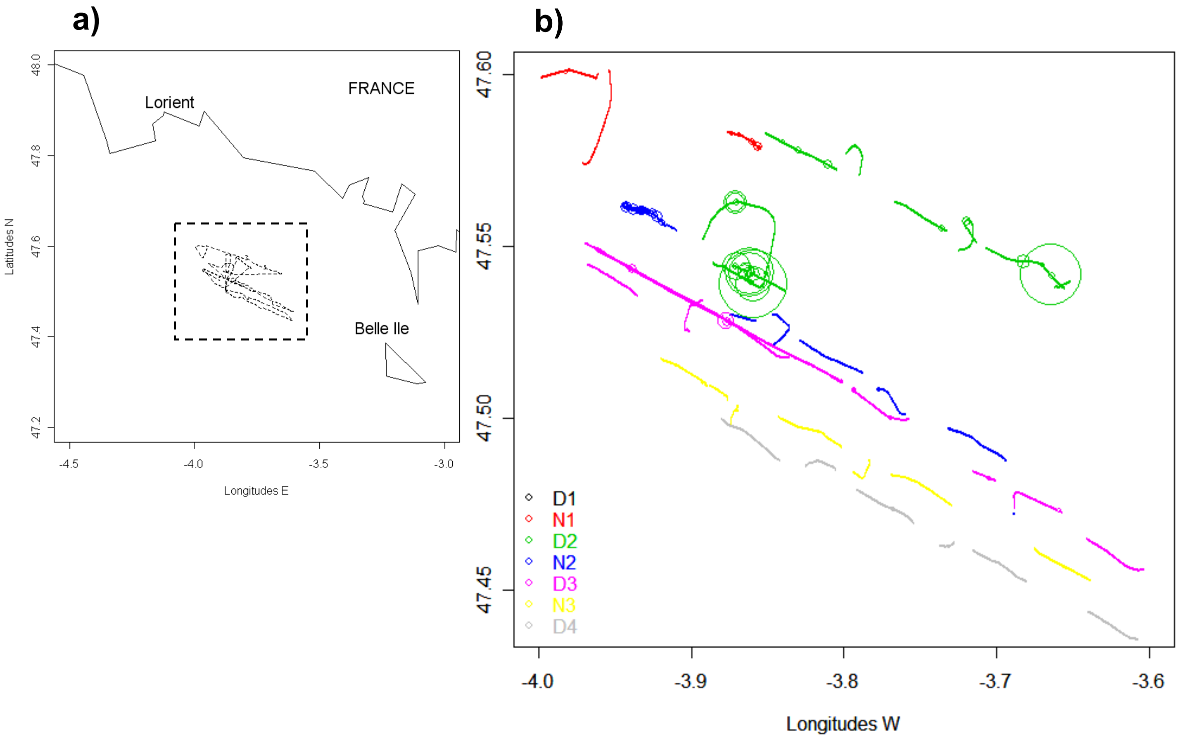
Figure 2. Species composition as a function of trawl hauls numbers for the different fishing vessels. For species names, refer to Table 1.

Figure 3. Relationship between daytime total ENASCs per haul and vessel (circles: Davidson, triangles: Océanie, crosses: Hebeilan) and total NASCs per haul recorded on F/V Davidson (straight line), computed in the case of hake dominated trawls.

Figure 4. Relationship between night-time total ENASCs per haul and vessel (circles: Davidson, triangles: Océanie, crosses: Hebeilan) and total NASCs per haul recorded on F/V Davidson (straight line) , computed in the case of hake dominated trawls.

Figure 5. Relationship between daytime total ENASCs per haul and vessel (circles: Davidson, triangles: Océanie, crosses: Hebeilan) and total NASCs per haul recorded on F/V Davidson (straight line) , computed in the case of horse mackerel dominated trawls.

Figure 6. Mean experimental variograms of acoustic densities recorded during hake-dominated trawl hauls in daytime (a) and night-time (b).


a)
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b)
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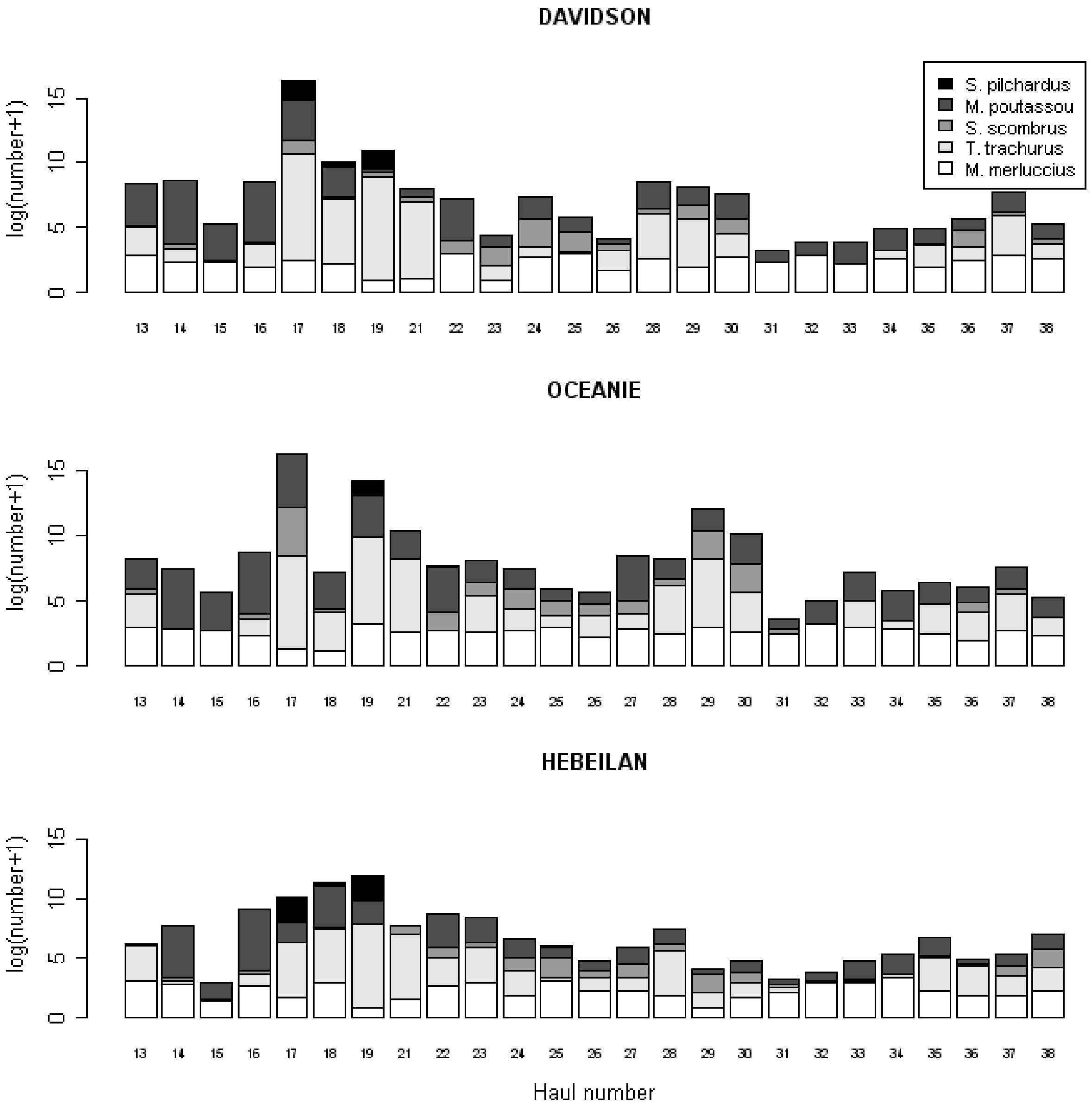
Figure 1.


DAVIDSON
S. pilchardus
M. poutassou
S. scombrus
T. trachurus
M. merluccius
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OCEANIE
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HEBEILAN
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Haul number

Figure 2.

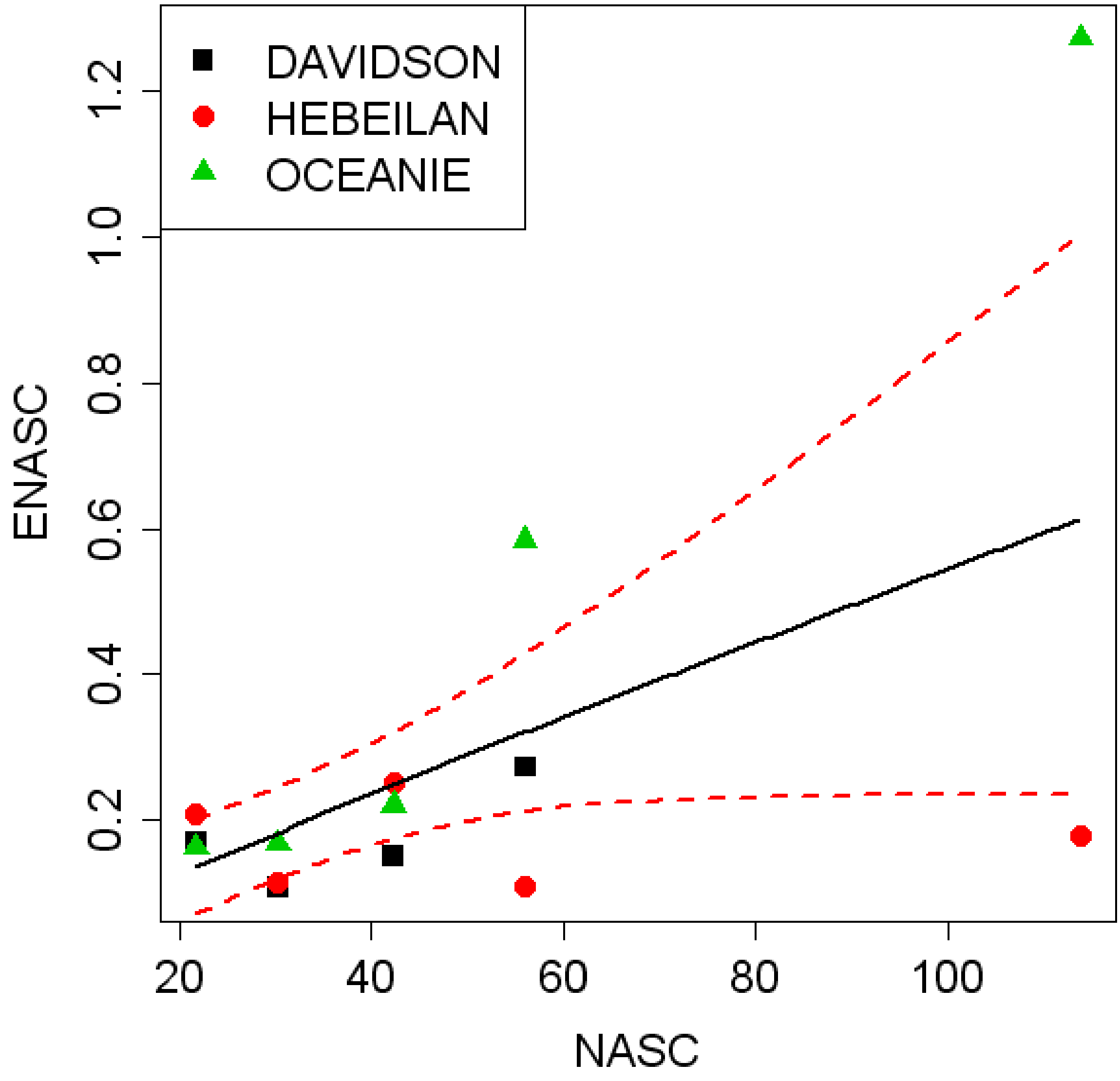
■ DAVIDSON
● HEBEILAN
▲ OCEANIE
ENASC
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Figure 3.

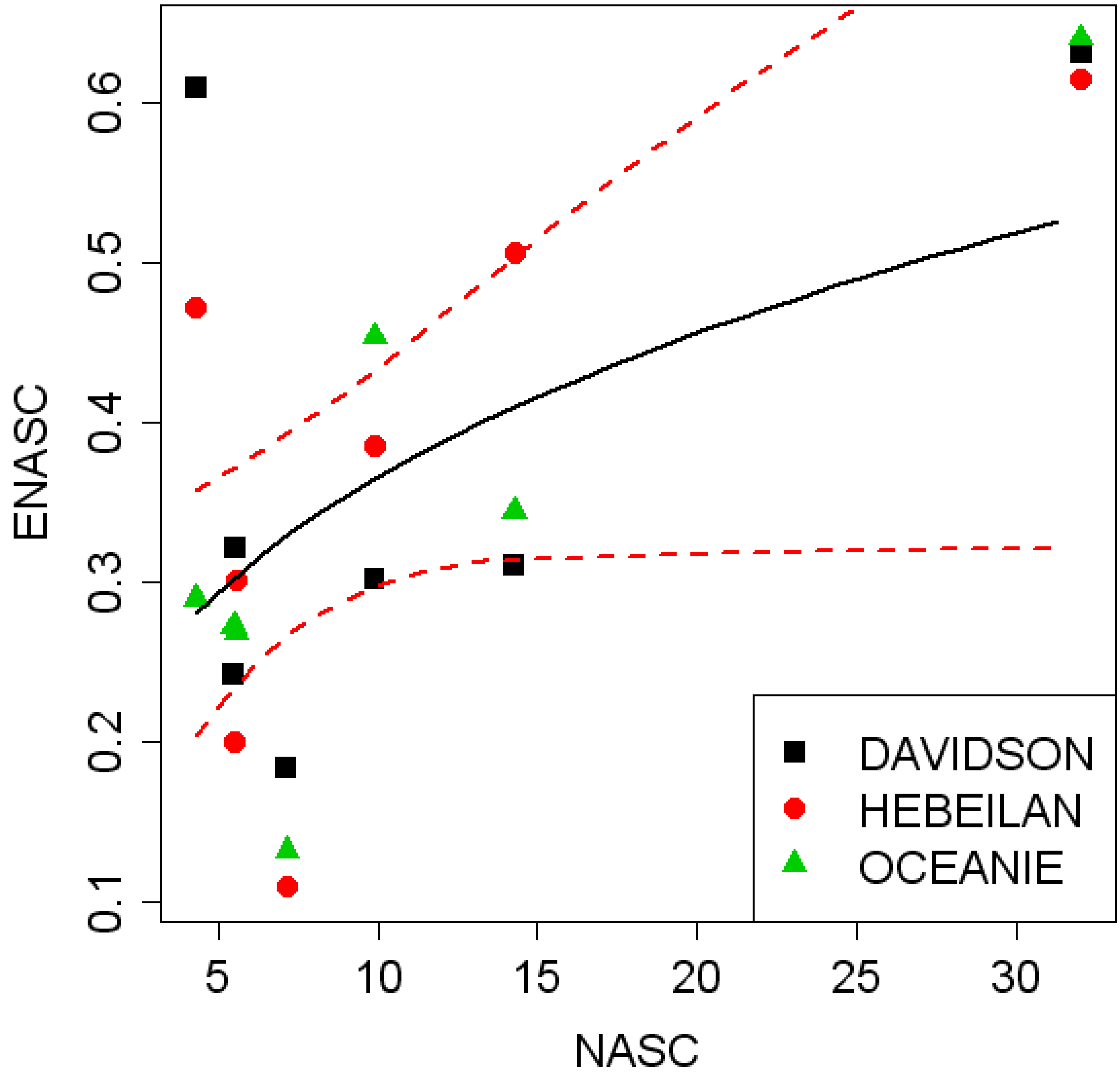
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Figure 4.

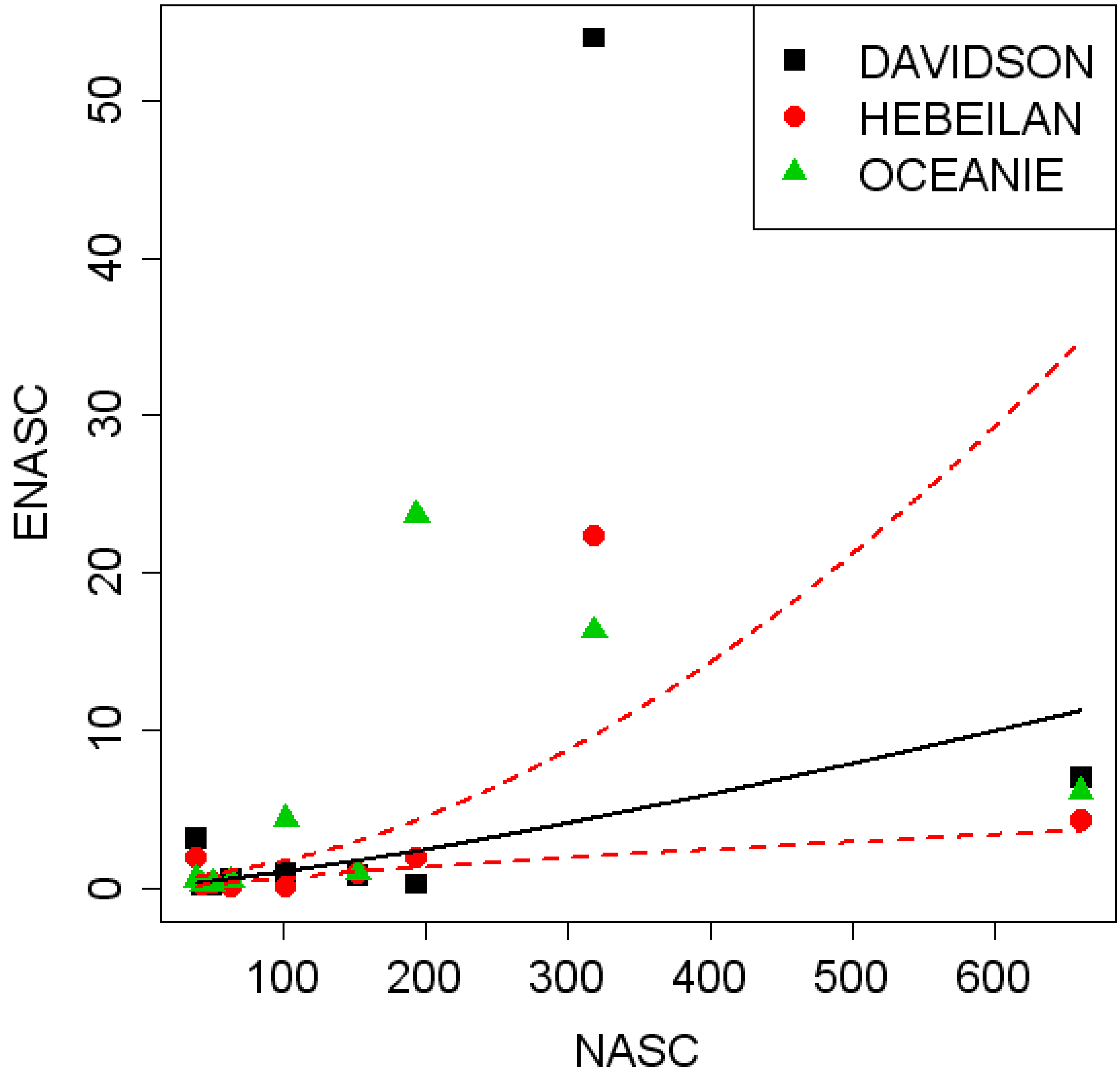
ENASC
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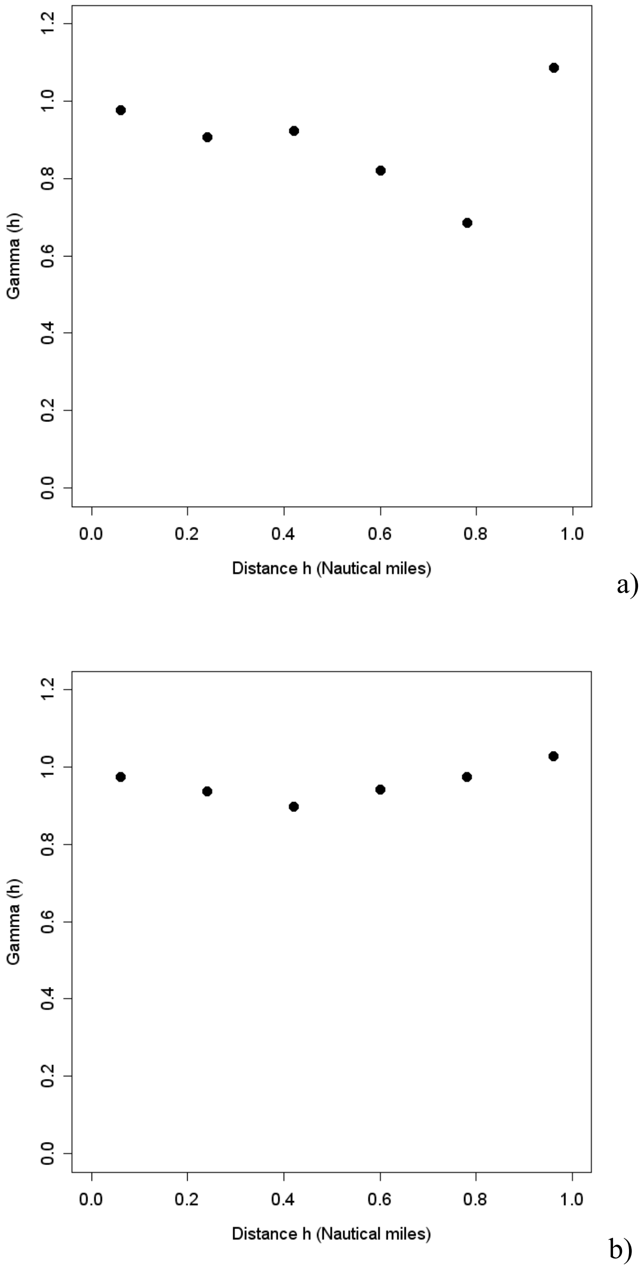
Figure 5.


Gamma (h)
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0.4
0.6
0.8
1.0
1.2
0.0
0.2
0.4
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0.8
1.0
Distance h (Nautical miles)
a)
Gamma (h)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
0.2
0.4
0.6
0.8
1.0
Distance h (Nautical miles)
b)

Figure 6.