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Vessel concentrations in the Javanese purse seine fishery: structuration through spatial approach

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Abstract — In the Java sea, pelagic fish are exploited by purse seiners. The resource is dispersed and has to be aggregated before being fished. Light is used to reach this objective. The purse seiners are mobile and fish in 'packs'. When concentrations of fish are found the fishing vessels gather in clusters. The spatial characterization of these clusters provides better understanding of the fishing strategy followed by the purse seiners. A point process approach is used to understand the clustering process and determine the life time of the clusters. The calculation of a density function defines the surface influenced by the cluster and estimates the intensity of the exploitation inside it. Clustering is the mark of the fishing phase that is defined by the significant divergence of the L-function from the Poisson process. In the fishery, such a result is observed when at least 15 purse seiners are gathered. Usually, the fishing phase lasts 4–6 days. The surface covered by the clusters represents a small part (15–25 %) of the surface that is accessible to the fleet. In these areas, the fishing intensity can reach high values (160 vessels × nautical mile^{-2}). © 2000 Ifremer/Cnrs/Inra/Ird/Cemagref/Éditions scientifiques et médicales Elsevier SAS

Fishing strategy / pelagic fish / spatial point process / clusters / Java Sea / Indonesia

Résumé — Les concentrations de navires dans la pêcherie des senneurs de Java : étude de leur structure à travers une approche spatiale. En mer de Java, les populations de poissons pélagiques sont exploitées depuis de nombreuses années par des flottilles de senneurs. La ressource y est dispersée et doit être agrégée avant d'être pêchée. L'attraction lumineuse est utilisée pour atteindre cet objectif. Les senneurs sont mobiles et pêchent en « meute ». Lorsque des concentrations de poisson sont détectées, les navires se regroupent. La caractérisation spatiale de ces regroupements permet d'améliorer notre connaissance des stratégies de pêche suivies par les navires. Une approche par processus ponctuel est utilisée pour comprendre le mécanisme d'agrégation des navires et déterminer la durée de vie de ces regroupements. Le calcul d'une fonction de densité nous permet de déterminer la zone d'influence du regroupement et d'y estimer l'intensité de l'exploitation. Le regroupement des navires est le signe distinctif de la phase de capture qui est caractérisée par la divergence significative de la fonction-L du processus de Poisson. Dans la pêcherie, cette divergence apparaît quand, au moins, 15 navires sont groupés. La phase de capture dure de 4 à 6 jours. Sur une zone de pêche, la surface couverte par les différents groupes de navires représente une faible partie de la surface accessible à la flottille. Dans ces zones, l'intensité de pêche peut atteindre de fortes valeurs (> 160 navires × mille^{-2}). © 2000 Ifremer/Cnrs/Inra/Ird/Cemagref/Éditions scientifiques et médicales Elsevier SAS

Stratégie de pêche / poissons pélagiques / modèle statistique spatial / regroupement / mer de Java / Indonésie

1. INTRODUCTION

In the Java Sea, most of the pelagic biomass is dispersed in numerous small shoals scattered in the whole water column [3]. They are often grouped in concentrations that are the targets of the Javanese purse seiners. Before being fished, pelagic fish have to be aggregated. Before 1987, the fishing operation was conducted in two stages by the purse seiners. In the first one, fish were aggregated below FADs (fish aggregating devices). Usually, aggregation lasted several days. In the second one, during the night preceding the seine net, fish were concentrated under the FAD with kerosene lamps [7].

In 1987, the introduction of electric lights shortened the time spent aggregating the fish. Nowadays, aggregation and concentration are merged in a single operation which lasts one night. The purse seiners are

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not linked anymore to the FADs and, during the fishing trip, they can prospect more than one fishing ground [6]. Purse seiners fish in 'packs' [8] in search of concentrations of fish. When such a structure is found, clusters of vessels occur.

The knowledge of the spatial structure of these clusters may help us to better understand the fishing strategy of the purse seiners. In order to achieve this objective, the study was carried out in two steps. In the first one, the determination of the life time of these clusters is undertaken. A spatial point process approach is used to characterize the clusters. Structuring and destructuring phases of the process are defined. In a second one, a density function is applied to estimate the fishing intensity reached inside the clusters and the area influenced by them.

2. MATERIALS AND METHODS

During the Pelfish project (Java Sea Pelagic Fishery Assessment Project), 19 acoustic cruises were performed. During the transects, the fishing zones of the Javanese purse seiners were crossed. For every cluster encountered, the purse seiners were radar located. The radar of the Indonesian R/V 'Bawal Putih I' has a range of 15 nautical miles. In the analysis, when two echoes were closer than the standard seine net length used in the fishery (600 m long) they were considered as belonging to the same boat and hence only one echo was recorded. Twenty-seven clusters were detected and sampled. Among them, 18 clusters detected at night, dawn or dusk were selected. At that time of the day, the sampled clusters represent vessels that are fishing (*table I* and *figure 1*). In December 1992 and 1993, in the Matasiri fishing ground, two clusters were sampled at 4-day intervals. The first plot was made in full fishing phase, the second at the end of the fishing phase when the number of fishing vessels decreases as they begin to disperse. In February 1995, in the Makassar strait, R/V 'Bawal Putih I' sampled a cluster when it began to structure. Figures for different phases of the clustering are available.

During acoustic cruises performed in October 1992 and January–February 1995, Masalembo and Makassar fishing zones were entirely covered over 4 and 7 days, respectively (*figure 2*). The two cruises give a comprehensive view of the cluster distribution in a fishing zone.

A spatial point process was performed to characterize the formation [5] and the duration of the clusters. A density function was developed and applied to determine the fishing intensity occurring inside the clusters and the surface they influenced.

2.1. Spatial point process

Spatial point process models are stochastic models of point patterns, i.e. sets of points scattered in the two- or three-dimensional space. Those patterns arise in many natural phenomena; classic examples include trees in a forest, cell nuclei in a tissue, stars and galaxies, etc.

Among point processes, the Poisson point process (PPP) stands out as a reference, in the same manner as

Table I. Location and main characteristics of the 18 clusters chosen for the present study. F, fishing phase; S, structuring phase; D, destructuring phase.

Fishing zone	Date	Time	No. vessels	Surface (n. mile^2)	λ (density) (vessel × n. mile^{-2})	Phase
Masalembo						
cluster I	19 October 1992	20h00	54	415	0.13	F
cluster II	20 October 1992	17h00	18	32	0.56	D
cluster III	21 October 1992	04h50	25	540	0.05	F
cluster IV	22 October 1992	19h00	77	720	0.11	F
fishing area			174	4 800	0.09	
Matasiri	4 November 1992	03h20	42	302	0.14	F
	9 November 1992	03h10	15	42	0.36	D
Matasiri	10 December 1992	20h50	13	39	0.33	D
China Sea	20 April 1993	22h00	106	636	0.17	F
Brondong	15 October 1993	18h00	16	86	0.19	F
Matasiri	11 November 1993	21h30	18	90	0.20	F
Matasiri	08 December 1993	17h00	42	84	0.50	F
	12 December 1993	07h00	19	43	0.40	D
Makassar						
cluster I	27 January 1995	07h00	65	132	0.49	F
cluster II	27 January 1995	10h00	33	55	0.60	F
cluster III	27 January 1995	17h30	12	86	0.14	S
cluster IV	31 January 1995	16h30	41	67	0.61	F
cluster V	1 February 1995	09h00	27	73	0.37	F
cluster VI	4 February 1995	16h30	32	50	0.60	F
fishing area			209	6 480	0.03	

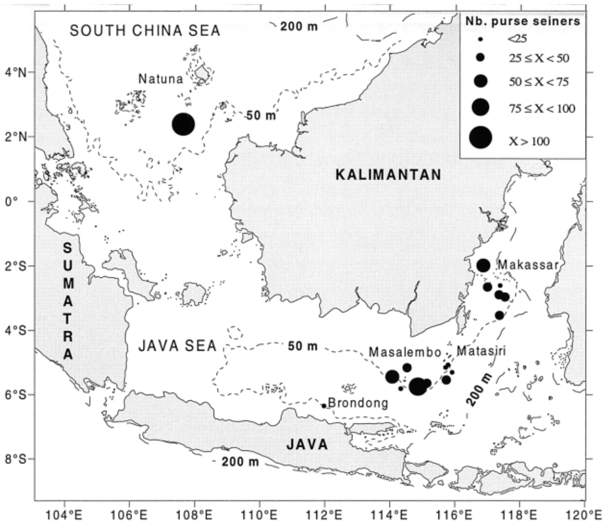

Figure 1. Location of the clusters sampled during the acoustic cruises carried out from 1992 to 1995 in the Java and South China Seas.

the Gaussian distribution among continuous distributions. It is characterized by a lack of interaction between points. Patterns exhibiting this property are described as 'completely random', so a given pattern has to be first compared to a Poisson point process before a more sophisticated model is considered. Thus one major interest of the Poisson point process lies in its use as a null hypothesis for statistical tests of interaction [1].

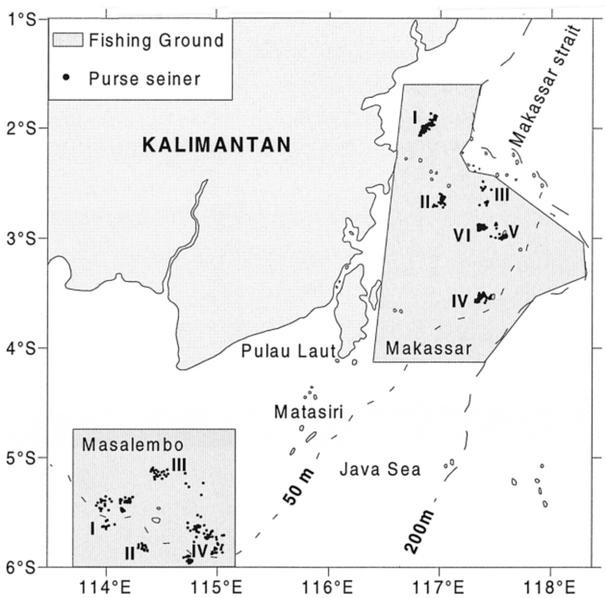

Figure 2. Location and characteristics of purse seiner clusters sampled during the acoustic cruises carried out in October 1992 on the Masalembo fishing ground and in January–February 1995 on the Makassar fishing ground.

We assume that all points (fishing vessels) of the point process are detected through the radar location and that vessel clusters are homogeneous and isotropic, which seems realistic at a small scale. To test the Poisson point process two analyses were performed.

2.2. L-function

Let n be the number of points (fishing vessels) over an area A (defined as the convex hull of the cluster). The density of vessels in the area A is estimated by:

$$\lambda = n/A$$

The spatial structure can be analysed through the L-function:

$$L(h) = \sqrt{n(h)/\lambda\pi}, \quad (h \geq 0)$$

where $n(h)$ is the number of points at a distance at most h from a generic point.

The L-function of a homogeneous Poisson field satisfies:

$$L(h) = h, \; (h \geq 0)$$

If $L(h) > h$ the points are clustered.

If $L(h) < h$ the points are more regularly distributed than in a Poisson point process.

Confidence limits were calculated using the formula of Ripley [9]

$$\tau = \sqrt{A}/n \times 1.45$$

If the L-function calculated for the point pattern is outside these confidence limits then the Poisson point process hypothesis must be rejected.

To perform the calculations we used the SPP (spatial point process) software developed by Petitgas and Lafont [4].

2.3. Dispersion index

To calculate this index [10], the area A corresponding to the vessel concentration is divided into k congruent squares. The side length (d) is chosen so that 80 % of the distances between one vessel and its nearest neighbours are inferior or equal to d.

The number of points n_i in each square is determined. Assuming a Poisson field, the n_is are independent and identically Poisson distributed. The index is expressed as:

$$I = (k - 1)\, s^2 / m$$

where k is the number of squares, m is the mean number of points per square and s^2 is the variance.

Table II. Values of the dispersion index (I) and the L-function (C, aggregative process; P, Poisson process) calculated for each cluster. Results of the χ^2 test performed on the dispersion index (C, aggregative process; P, Poisson process). *k*, number of squares; *N*, number of purse seiners.

Cruises	Date	*k*	*N*	*I*	χ^2	$\lambda A/k$	*h*	L-function
Masalembo								
cluster I	19 October 1992	49	54	116.9	C	1.1	0.05	C
cluster II	20 October 1992	9	18	18.0	C	2.0	0.03	P
cluster III	21 October 1992	20	25	145.5	C	1.25	0.10	C
cluster IV	22 October 1992	20	77	149.2	C	3.85	0.10	C
fishing area		120	174	895.0	C	1.42	0.10	C
Matasiri	4 November 1992	36	42	105.5	C	1.17	0.04	C
	9 November 1992	12	15	57.8	C	1.25	0.04	C
Matasiri	10 December 1992	9	13	12.7	P	1.2	0.05	P
China Sea	20 April 1993	88	106	401.4	C	1.2	0.05	C
Brondong	15 October 1993	10	16	14.0	P	1.6	0.05	P
Matasiri	11 November 1993	15	18	32.0	C	1.16	.05	C
Matasiri	8 December 1993	20	42	126.6	C	1.44	0.04	C
	12 December 1993	18	19	29.2	P	1.06	0.03	P
Makassar								
cluster I	27 January 1995	20	65	94.6	C	3.25	0.05	C
cluster II	27 January 1995	20	33	69.4	C	1.65	0.04	C
cluster III	27 January 1995	10	12	16.3	P	1.20	0.05	P
cluster IV	31 January 1995	16	41	60.9	C	2.56	0.04	C
cluster V	01 February 1995	16	27	118.0	C	1.69	0.05	C
cluster VI	04 February 1995	24	32	38.6	C	1.33	0.02	C
fishing area		144	209	2 366	C	1.45	0.10	C

The Poisson hypothesis is rejected if

$$I > \chi^2_{k-1,\alpha} \text{ or } I < \chi^2_{k-1,1-\alpha}$$

with $\alpha = 0.05$.

2.4. Density function

In order to better visualize the vessel clusters, a density function has been calculated. To each vessel is assigned a function taken as normal bivariate density of unit mass expressed as:

$$F(D) = \frac{1}{h^2 2\pi} \exp\left\{ \frac{-(x^2 + y^2)}{2h^2} \right\}$$

where h is the limit of attraction in the two directions (equal to the d of the dispersion index), x is the longitude and y the latitude.

The density function represents the sum of the individual functions. Thus the density values are directly interpretable as numbers of vessels per unit area. The program (in S language) used to compute the density function is given in the Appendix. It allows the density function of the cluster to be traced and the area influenced by the fishing vessels to be estimated.

3. RESULTS

In the *table II* are gathered the results of the Chi-square test performed on the dispersion index calculated for each cluster and the two fishing zones. During the exploitation, they show that the point pattern of each cluster differs significantly from the Poisson process. At the end and the beginning of the aggregation this significance disappears. These results are confirmed by the L-functions calculated for the same structures.

3.1. Clusters

All curves show a similar pattern; that fact is interpreted as significant. When the seiners are fishing, at a short distance the L-function is above the Poisson line and stays outside its confidence limits. Around an arbitrary vessel, at a short distance, there is on average more vessels than a pure random process would generate (*figure 3a, b*).

When fishing vessels begin to disperse and structure, the L-function stays inside the confidence limits of the Poisson process even at a short distance. In other words around an arbitrary vessel a pure random process still occurs (*figure 3c, d*).

3.2. Fishing zones

The L-function stays above the Poisson line and outside its confidence limits even at a large distance (*figure 4*). The fishery is not exploiting in an homogeneous way, even randomly, the distribution area of the fish. The fishing strategy that is founded on the presence of shoals and exploits the gregarious behaviour of the fish induces a structuration of the fleet inside the fishing ground.

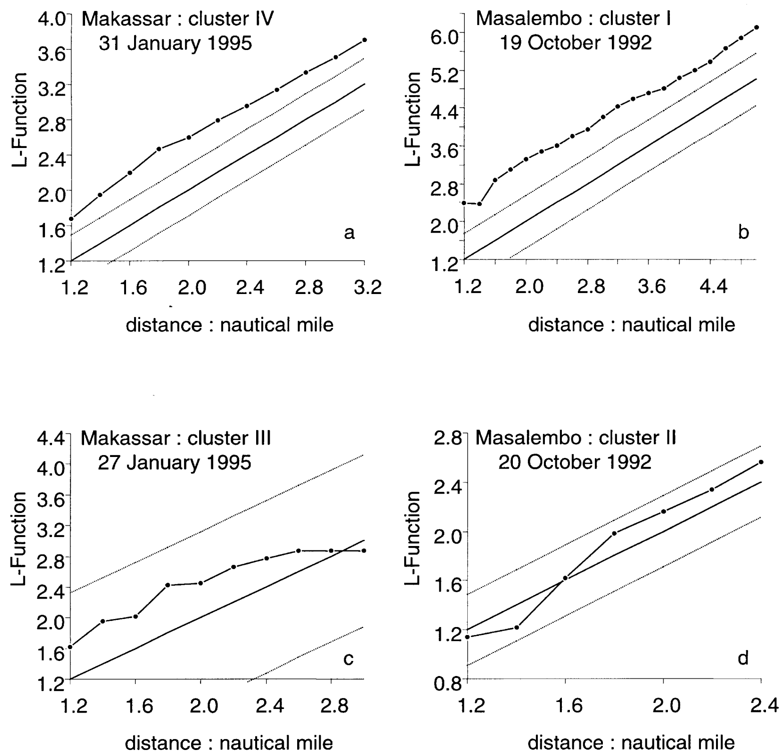

Figure 3. L-functions of clusters in different exploitation phase (a, b, fishing; c, structuring; d, destructuring). The diagonal line represents the L-function for a Poisson point process. The dashed lines represent the confidence limits of the Poisson line.

3.3. Density function

The repartition of the fishing vessels inside the clusters is not homogeneous. Shapes are diverse and clusters can include more than one nucleus (*figure 5*). In these nuclei, the density can reach more than 160 vessels × nautical mile^{-2}. The surface influenced by such structures is highly variable and depends on the number of vessels but also on their position among them.

4. DISCUSSION

During our study, the L-function curves are consistently comparable. This means that we may consider each cluster as a realization of the same underlying point process. The clustering is an aggregative process which leads the L-function to diverge significantly from the Poisson process. In the Javanese seiner fishery this result is reached when at least 15 vessels are gathered. Then the life of a cluster can be separated into three phases: structuring and destructuring phases which are characterized by fishing vessels randomly distributed, and the exploitation phase by fishing vessels which are aggregated. Spatial point process seems a good approach to estimate precisely the duration of the exploitation phase.

There was time lag between each cluster and each presents a different number of vessels. That means that the way the vessels are spatially organized is repro-

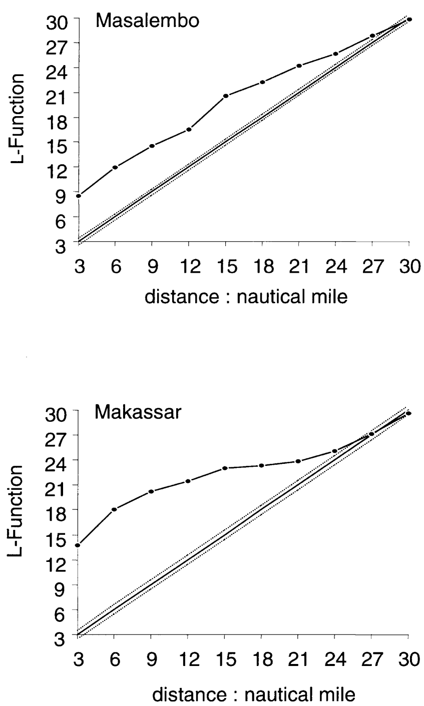

Figure 4. L-functions calculated on the sum of clusters sampled during acoustic cruises on the Masalembo fishing ground in October 1992 and the Makassar fishing ground in January–February 1995. The diagonal line represents the L-function for a Poisson point process. The dashed lines represent the confidence limits of the Poisson line.

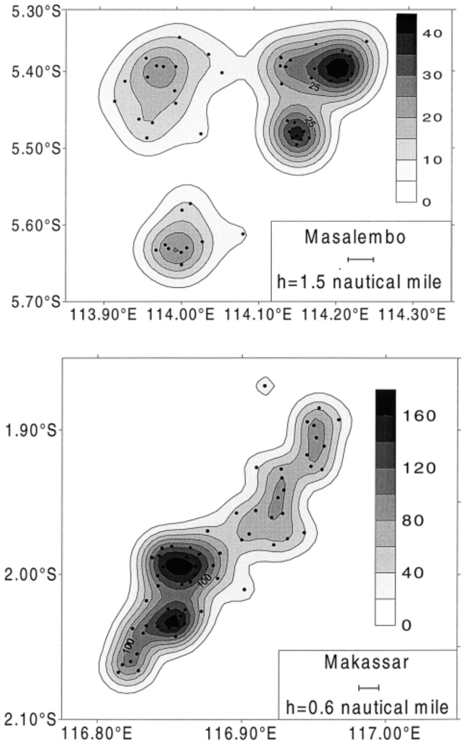

Figure 5. Density functions calculated for different clusters of purse seiners sampled during acoustic cruises. The isolines represent the number of seiners × nautical mile^{-2}. h is the limit of the attraction in the two directions.

ducible. In such fisheries, the fishing activity is not individual but fleet conducted. It can be compared to the aggregative answer already found in the predator–prey relationship. The fishermen behave as predators and exert a choice between the areas poor in prey and those rich in prey. Numerous works show that many predators concentrate or hunt in the most profitable zones. In his work, Hassell [2] presented some results on such aggregative behaviour of the predator.

During the fishing phase, the purse seiners are concentrated on a small part of the fishing ground. In October 1992, during the Masalembo cruise, the area exploited by the clusters represents 25 % of the fishing ground surface. In January–February 1995, during the Makassar cruise, this value reached 15 % of the surface available (*figure 6*). Then, compared to the area prospected during the searching phase, the surface exploited is small. In the Javanese pelagic fishery, it seems that strong interactions exist between the way the pelagic population occupies the space and the spatial strategy followed by the seiners.

In this fishery, the catch by set is impossible to obtain. When such information is available a marked point process may be applied. In that fishery, the knowledge of some practical parameters such as the switch on–switch off function of the electric lights, could be used to estimate precisely the area influenced by the clusters and study whether competition can exist among fishing vessels forming a cluster.

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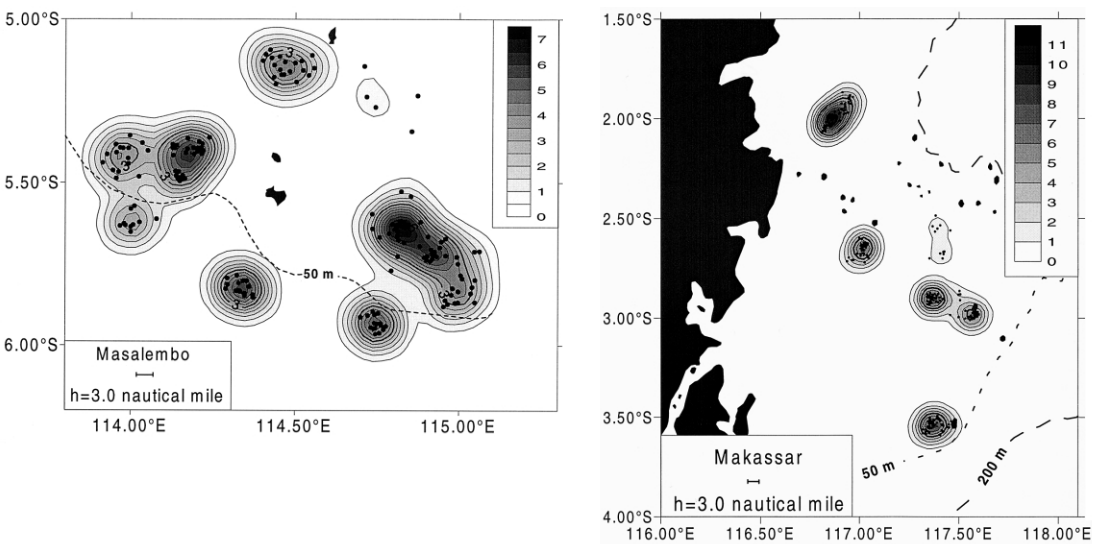

Figure 6. Surface of influence of the clusters located on: a) the Masalembo fishing ground during the October 1992 acoustic cruise; b) the Makassar fishing ground during the January–February 1995 acoustic cruise. h, limit of the attraction in the two directions. The isolines represent the number of seiners × nautical mile^{-2}.

APPENDIX

Density function used to determine the surface influenced by the clusters of purse seiners algorithm language S +

```
function(x, nx = 20, ny = 20, margin = 0.05, h = d)
#
#      density2d
#
# estimation of the bidimensional density
# x: matrix 2 columns (latitude, longitude)
#
#
{
   xrange < – max(x[0, 1]) – min(x[0, 1])
   yrange < – max(x[0, 2]) – min(x[0, 2])
   xmin < – min(x[0, 1]) – xrange * margin
   xmax < – max(x[0, 1]) + xrange * margin
   ymin < – min(x[0, 2]) – yrange * margin
   ymax < – max(x[0, 2]) + yrange * margin
   xsteP < – (xmax – xmin)/(nx – 1)
   ysteP < – (ymax – ymin)/(ny – 1)
   xx < – xmin + (0:(nx – 1)) * xstep
   yy < – ymin + (0:(ny – 1)) * ystep
   g < – matrix(0, ncol = nx, nrow = ny)
   n < – dim(x)[(1)]
   for(i in 1:n) {
      coefx < – dnorm(xx – x[i, 1], mean = 0, sd = h)
      coefy < – dnorm(yy – x[i, 2], mean = 0, sd = h)
      g < – g + coefy%*% t(coefx)/n
}
   return(list(x = xx, y = yy, z = t(g)))
}
```

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