Modelling the distribution of alfonsino, *Beryx splendens*, over the seamounts of New Caledonia

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Abstract.— Commercial and scientific bottom longline catches of alfonsino, *Beryx splendens,* from seamounts off New Caledonia were sampled to study length-frequency distributions. A total of 14,674 fish were measured. CPUE of *Beryx splendens* on two seamounts is modelled in terms of length and depth. The data show that mean length increases with depth; this is well described by a bivariate normal model that estimates catch for a given seamount. In addition, the data show that mean length also varies with the depth of the top of seamounts; this is described by a recursive model that is designed to predict approximate catch for any seamount. The limitations of both models are discussed, particularly with regard to temporal variation.

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A bottom longline fishery operated on the seamounts of the Exclusive Economic Zone (EEZ) of New Caledonia from February 1988 to July 1991.[1] Three vessels were involved but only one vessel was operated at any given time. The fishing effort, which totalled 4,691,635 hooks, focused on five seamounts (B, C, D, J, and K) whose summits are located at depths ranging from 500 to 750 m (Fig. 1). The target species, alfonsino, *Beryx splendens*, accounted for 92% of the catch by weight. This species has a worldwide distribution, from the equator to the temperate latitudes, and is fished by bottom trawl or longline. Alfonsino generally occupies waters between 200 and 800 m, although it has been caught at depths of only 25 m and as deep as 1,240 m (Busakhin, 1982). Some authors have noted an increase in mean length with depth[2] (Yamamoto et al., 1978, Seki and Tagami, 1986), a trend which has been observed in other fishes (Heincke, 1913), particularly some deep-water demersal species[3, 4, 5] (Ralston and Williams, 1988). There have been few studies relating the size distribution of alfonsino to depth. The objective of this paper is to describe an approach for estimating the abundance of alfonsino by modelling its distribution in terms of fork length and depth of capture. A bivariate normal model describes this distribution for a given seamount and a recursive model predicts catch on any seamount.

Material and methods

Data

Alfonsino were captured with longline gear (Fig. 2). The main line, averaging 4,000 m, was held on the bottom by means of terminal anchors and regularly spaced heavy sinkers that delimited five equal line sections. During a fishing trip

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[1] Grandperrin, R., and P. Lehodey. 1993. Étude de la pêcherie de poissons profonds dans la zone économique de Nouvelle-Calédonie. Rapport final. Contrat de recherche ORSTOM / Territoire de Nouvelle-Calédonie. Nouméa: ORSTOM, Conv. Sci. Mer, Biol. Mar. 9, 321 p.

[2] Masuzawa, T., Y. Kurata, and K. Onishi. 1975. Results of group study on population of demersal fishes in water from Sagami Bay to the southern Izu Islands—population ecology of Japanese alfonsin and other demersal fishes. Japan Aquatic Resources Conserv. Assoc. Fish. Res. Paper 28, 105 p. [English translation held at Fisheries Research Centre Library, MAF, P.O. Box 297, Wellington].

[3] Brouard, F., and R. Grandperrin. 1985. Deep bottom fishes of the outer reef slope in Vanuatu. South Pacific Commission 17th Regional Technical Meeting on Fisheries, W P 12, 127 p.

[4] Clark, M. R., and K. J. King. 1989. Deepwater fish resources off the North Island, New Zealand: results of a trawl survey, May 1985 to June 1986. N.Z. Fish. Tech. Rep. 11, 55 p.

[5] Dalzell, P., and G. L. Preston. 1992. Deep reef slope fishery resources of the South Pacific. South Pacific Comm. Inshore Fish. Res. Project. Tech. Doc. 2, 299 p.

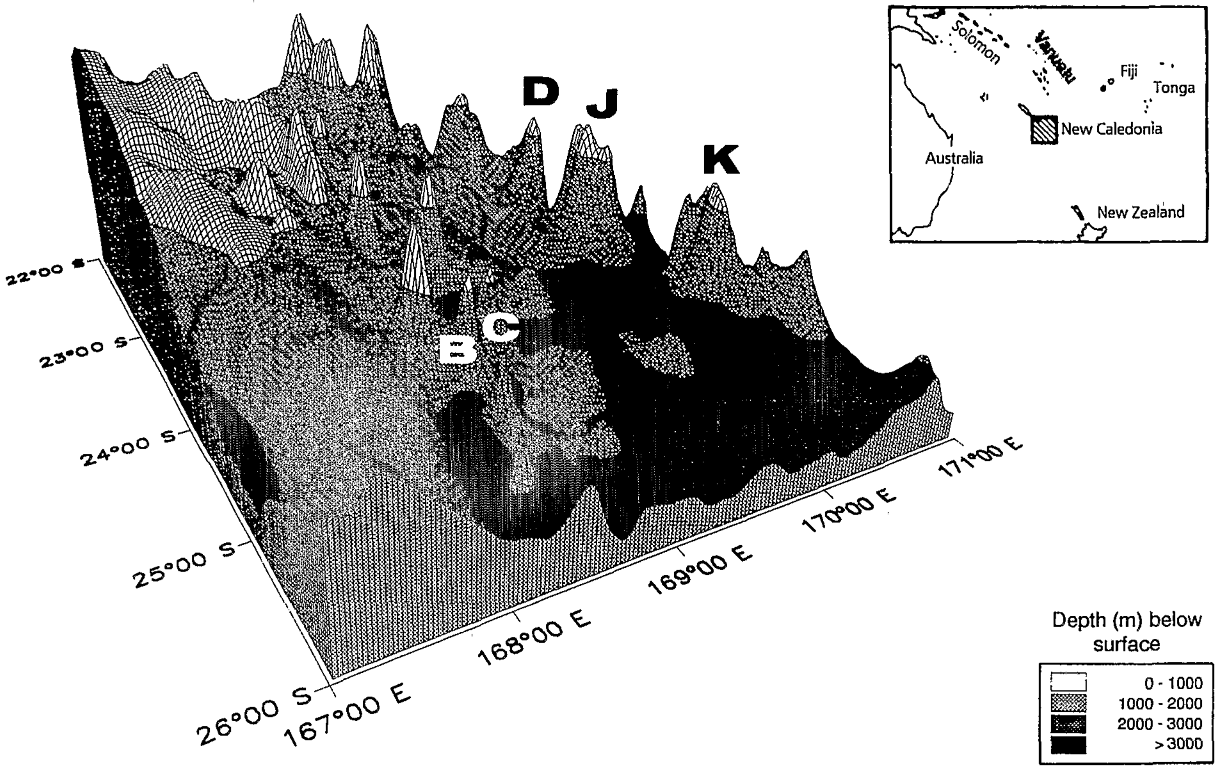

Figure 1

Main seamounts fished for alfonsino, *Beryx splendens,* by bottom longline in New Caledonia.

made by the longliner *Humboldt* from May to July 1991 over seamounts B, C, D, J, and K,[6] the depth profile of the bottom was recorded on an echosounder as the line was set. The position and the depth at the exact time the terminal anchors and intermediate sinkers were thrown overboard were also recorded. The longliner *Humboldt* was equipped with a Doppler sonar current indicator which provided current velocity and direction at three selected depths. Data recorded suggest that the current velocity rapidly decreased with depth (Fig. 3A) and that horizontal drift was probably minimal.[6] On 23 occasions over the total of 73 longline sets, the depth of the bottom was recorded at the time the buoy was grabbed at the beginning of retrieval. This depth was compared with the depth of the corresponding terminal anchor recorded when the line was set. Depth difference was less than 10 m for 74 % of the paired comparisons (Fig. 3B) which indicates that either the drift of the line during sinking was limited or the slope of the bottom was slight. Therefore, despite the lack of a maximum depth recorder to determine the actual depth of the main line (Somerton and Kikkawa, 1992), it was reasonable to assume that its configuration was similar to the depth profile indicated by the echosounder.

The estimated depth of the sinkers was used to allocate a mean value of depth of capture $\bar{d}_i = 1/2\ (d_i + d_{i+1})$ to all the fish caught on the same 800-m line section (Fig. 2). Ten meters, which is roughly half the length of the branch lines, was then added to each mean depth of capture $\bar{d}_i$ to correct for bias introduced by the fact that catches may occur at any hook level. Figure 3C gives the depth variation within each section. Eighty-one percent of the variation in depth is less than 15 m and 92% is within the 0–25 m range. This indicates that in most cases the longline was nearly horizontal with the bottom. Therefore, the allocation of a single depth of capture to all fish caught on the same line section seems reasonable, particularly as the depth of capture data were aggregated into 25-m depth classes for analysis. Dur-

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[6] Lehodey, P. 1991. Mission d'observations halieutiques sur le palangrier *Humboldt*. Campagne de pêche du 30 mai au 12 juillet 1991, Nouméa. ORSTOM Rapp. Missions, Sci. Mer Biol., Mar. 8, 44 p.

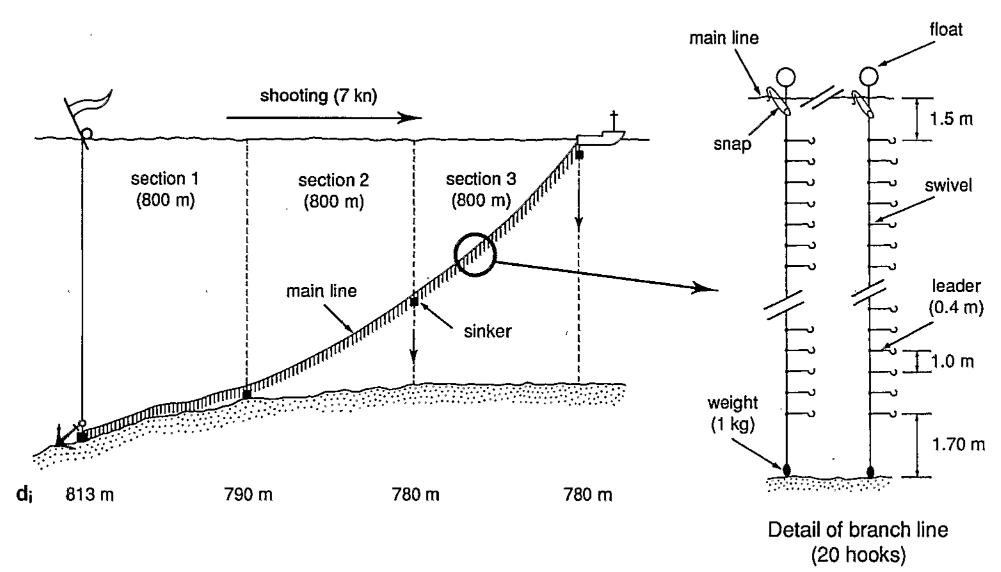

Figure 2

Longline gear employed from the longliner *Humboldt* during a set (15) on 7 June 1991 on seamount K (lat. 24°43'S; long. 170°06'E) and detail of a branch line. Main line is 4,000 m long and divided into five sections (each section has 840 hooks [42 branch lines × 20 hooks] and is 800 m long). d_i depth recorded on the echosounder at time t_i when sinker was thrown overboard; $\overline{d_i} = 1/2\,(d_i + d_{i+1}) + 10$ = mean depth of capture allocated to all fish hooked on section *i*.

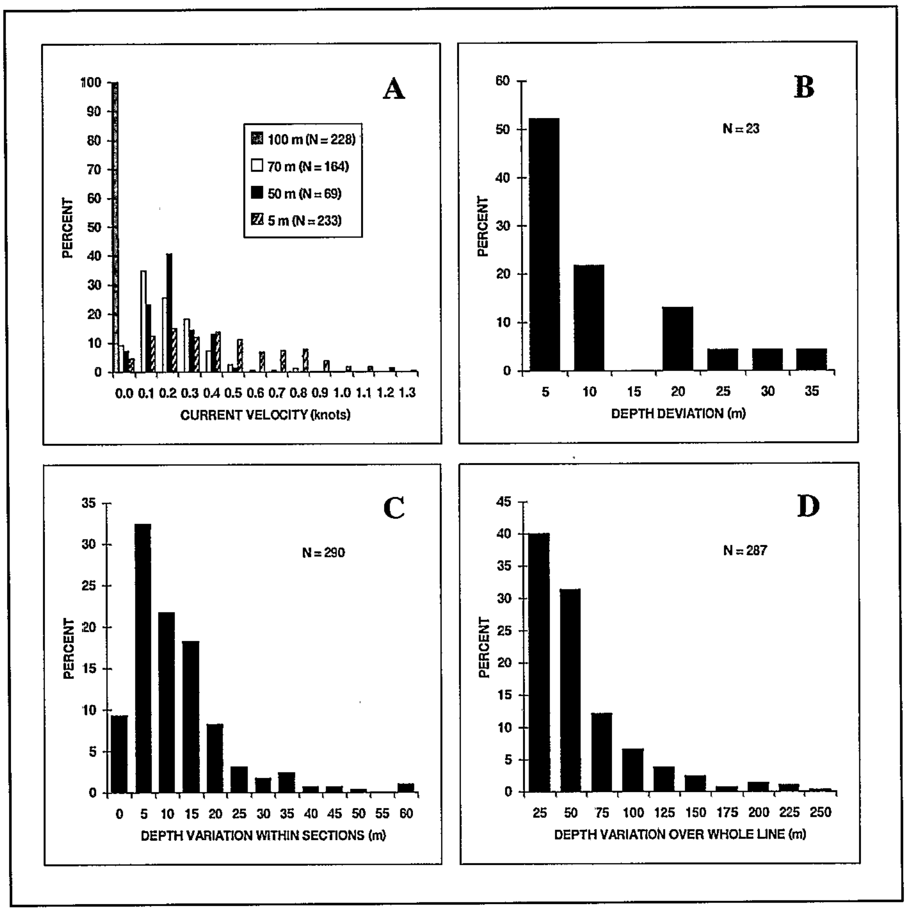

Figure 3

Measurements taken to assess the deviation between the depth profile recorded on the echosounder and the actual configuration of the longline on the bottom: (**A**) current velocity from the Doppler sonar current indicator recorded at different depths during the settings of the longline by the *Humboldt* (n=694 current measurements); (**B**) deviations between the depth of the terminal anchor recorded when the line was set and the depth of the bottom recorded at the time the corresponding buoy was grabbed at the begining of retrieval (n=23 sets); (**C**) depth variations within sections recorded during the fishing cruise carried out by the longliner *Humboldt* (n=290 line sections of 800 m each); (**D**) depth variations (differences between maximum and minimum depths) for the whole line recorded during the fishing cruises carried out by the longliners *Hokko Maru* and *Fukuju Maru* (n=287 longlines of 4,000 m).

ing two other commercial cruises conducted by the longliners *Hokko Maru* and *Fukuju Maru*, observers recorded the maximum and minimum depths reached by the longline[7, 8] (Fig. 3D).

Fork length (FL) was measured on a total of 14,674 alfonsino. During the commercial fishing trips, fish to be measured were randomly sampled from each set. When there were only a few fish, they were all measured. As the samples varied in size between sets, the length-frequency distribution of all the alfonsino caught was estimated by multiplying the number in the sample by the ratio of the total number of alfonsino caught to the total number of alfonsino measured for each longline set. During several scientific cruises all of the fish were measured.[1] Because all the depth zones were not sampled in the same way, catch per unit of effort (CPUE=number of fish caught per 100,000 hooks) was taken as the abundance index.

The data collected during the *Humboldt* cruise was used to model the distribution of CPUE in terms of length and depth over seamounts. The models were validated with data generated by the scientific cruises and with data collected on board the two additional commercial boats, *Hokko Maru* and *Fukuju Maru*. These commercial data are less precise because only maximum and minimum longline depths were recorded.

Preliminary data analysis

Table 1 shows the mean fork length by depth zone for each seamount sampled during the *Humboldt* cruise. This table suggests a significant increase in mean length with depth on each seamount. In order to model this increase, the data must be as representative as possible of the fish population over its depth range. For this reason, only data recorded for seamounts B and J were used for modelling the increase in length with depth.

Table 1

Analysis of variance and multiple comparisons of mean fork length (cm) of alfonsino, *Beryx splendens,* sampled on five seamounts during the *Humboldt* fishing cruise (sample size in parentheses).

	Seamount					
Water depth of top (m)	B [502 m]	C [560 m]	J [630 m]	D [630 m]	K [710 m]	α*
< 525	33.27 (52)					
525–549	34.90 (665)					
550–574	37.11 (635)	34.72 (405)				0.0001
575–599	38.08 (82)	36.78 (1083)				0.0007
600–624	40.39 (125)	38.95 (74)	35.23 (262)			0.0001
625–649			36.24 (462)			
650–674			37.55 (913)	35.73 (138)		0.0001
675–699			38.16 (115)	35.54 (295)		0.0001
700–724						
725–749			40.60 (205)			
750–774					38.21 (309)	
775–799					39.90 (308)	
+ 800					40.57 (53)	
α*	0.0001	0.0001	0.0001	0.4979	0.0001	

* If α is less than 0.05 then the hypothesis that the means are the same in all classes is rejected. All individual means were compared pairwise with the multiple comparison test of Tukey-Kramer (in SAS, 1988). The shaded boxes indicate that the two included means are not significantly different at the 0.05 level.

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[7] Anonymous. 1988. Rapport de la campagne de pêche à la palangre profonde dans la zone économique de la Nouvelle-Calédonie. *Hokko Maru* 107: février–mai 1988. Territoire de Nouvelle-Calédonie, Service Territorial de la Marine Marchande et des Pêches Maritimes, 57 p.

[8] Laboute, P. 1989. Mission d'observation halieutique sur le palangrier japonais *Fukuju Maru* du 21 nov. au 12 déc. 1988, Nouméa. ORSTOM Rapp. Missions, Sci. Mer Biol. Mar. 2, 15 p.

CPUE distributions by size class and depth zone over seamounts B and J from the *Humboldt* are shown in Figure 4. A preliminary examination of the data revealed that they fitted portions of curves conforming to a normal distribution. It was therefore assumed that for a given seamount the CPUE, in terms of length and depth, was distributed over a surface described by a bivariate normal distribution function delimited by the maximum and minimum of lengths and depths sampled. This assumption is the basis of the first modelling exercise ("bivariate normal model").

Table 1 also shows that, for a given absolute depth, mean length significantly decreases as the depth of the top of the seamount increases. This decrease suggests that the length distribution depends both on the absolute depth (in relation to the sea surface) and on the depth of the top of the seamount. Consequently, the bivariate normal model constructed for a given seamount may not be applicable to other seamounts whose summits lie at different depths. It is therefore necessary to construct a more general model (referred to as the "recursive model") which would predict extrapolated estimates of CPUE over any seamount by taking into account both the absolute depth of the water column and the depth of the top of the seamount. Temporal validation of these two models requires data that were not used during model construction but were collected in the same area at different periods. Data collected on board RV *Alis* and the fishing vessels *Hokko Maru* and *Fukuju Maru* were used for model validation.

Modelling method

Bivariate normal model In the bivariate normal model, CPUE by length and depth are calculated on the basis of a bivariate normal distribution defined by the density function (1)

$$B(x_l,x_d)=\frac{1}{2\,\pi\,\sigma_l\,\sigma_d\,\sqrt{1-\rho^2}}$$

$$\exp\left\{-\frac{1}{2\left(1-\rho^2\right)}\left[\left(\frac{x_l-\mu_l}{\sigma_l}\right)^2-2\rho\frac{(x_l-\mu_l)(x_d-\mu_d)}{\sigma_l\,\sigma_d}\right.\right. \quad (1)$$

$$\left.\left.+\left(\frac{(x_d-\mu_d)}{\sigma_d}\right)^2\right]\right\},$$

where x_l is the length, x_d is the depth, μ_l is the mean length, σ_l is the standard deviation of length, μ_d is the mean depth, σ_d is the standard deviation of depth, and ρ is the regression coefficient of length on depth. Because sampling of the seamounts is limited upwards by their summit (D_s) and downwards by the maximum depth accessible with the bottom longline (D_a), CPUE distributions will be modelled by a portion of the bivariate normal distribution (2)

$$\begin{cases}\mathrm{CPUE}_{\mathrm{est}}\,(x_l,x_d) \;=\; 0 & \text{for } x_d>D_a \text{ or } x_d<D_s\\ \mathrm{CPUE}_{\mathrm{est}}\,(x_l,x_d) \;=\; \lambda\,B(x_l,x_d) & \text{for } D_s\le x_d\le D_a\end{cases} \tag{2}$$

where λ represents the theoretical cumulative CPUE estimated over the field of definition of the entire bivariate normal distribution. The parameters λ, μ_l, σ_l, μ_d, σ_d and ρ were estimated by a nonlinear regression by using an iterative algorithm for sum of squares errors (SSE) minimization (SAS, 1988).

Recursive model The recursive model should allow estimation of alfonsino CPUE by size class for seamounts for which no data are available except the depth of their summit. The size structure variation shown in Table 1 should be taken into account in the development of this model, i.e. 1) for a given seamount, mean length increases with depth and 2) for a given depth zone, mean length decreases as the depth of the top of the seamount increases. In theory, the distribution of a population of alfonsino over any seamount could then be taken as the superposition of the distributions of two subpopulations: one population would be influenced only by the absolute depth while the other would be influenced by the depth of the top of the seamount. This model attempts to explain how the fish population of a given seamount would in theory redistribute itself if it were to migrate and settle on another seamount. Consider a hypothetical population whose cumulative CPUE (λ_0) by length and depth is distributed over its seamount of origin according to a bivariate normal distribution function of unknown μ_l, σ_l, μ_d, σ_d, and ρ parameters. For the estimation of these parameters, the top of the hypothetical original seamount will be assumed to be exactly level with the sea surface in order to include the entire depth zone that could be inhabited by alfonsino. The new CPUE distribution on seamounts *j*, *j*+1, etc. . . (Fig. 5) will depend on the initial parameters of the distribution over the original seamount as well as on parameter *p*, the probability that the fish will redistribute according to absolute depth, and (1–*p*), the probability that the fish will redistribute according to the depth of the top of the seamount. At each "leap" to a deeper seamount (from *j* to *j*+1), the subpopulation inhabiting a given depth zone D_i will split into two groups: one group will stay in the same depth zone D_i with a probability *p* (or will migrate elsewhere if this zone is no longer available on the new seamount) and the other

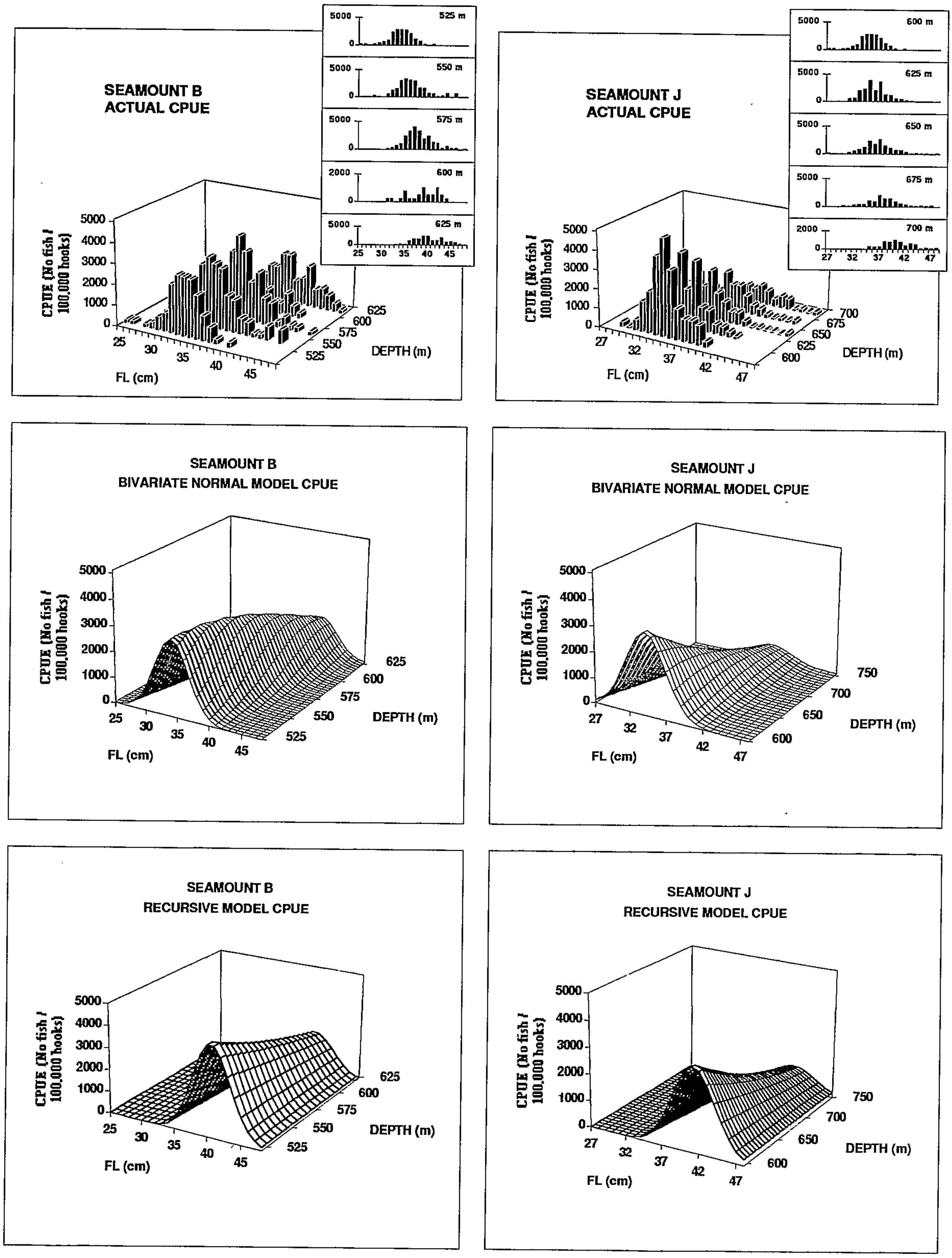

Figure 4

Actual CPUE for alfonsino, *Beryx splendens,* by fork length (cm) and depth (m), recorded on seamounts B and J during the fishing cruise carried out by the longliner *Humboldt,* and predicted CPUE from the bivariate normal model and the recursive model.

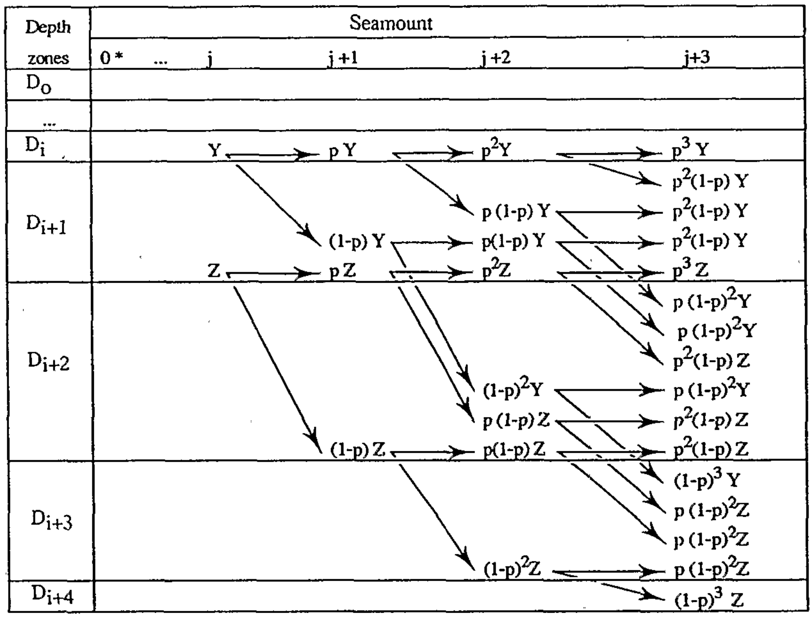

Figure 5

Changes in distribution of alfonsino, *Beryx splendens,* according to the recursive model of two subpopulations Y and Z that migrate from a seamount j to deeper seamounts $j+1, j+2, j+3$. Y=subpopulation distributed on a seamount j at absolute depth D_i; Z=subpopulation distributed on a seamount j at absolute depth D_{i+1}; p=probability that fish will redistribute according to absolute depth; $1-p$=probability that fish will redistribute according to the depth of the top of the seamount; *=original seamount.

group will move down to zone D_{i+1} with a probability $1-p$ (Fig. 5). Thus, it is possible to determine the CPUE ($X_{i,j,k}$) for the population of a depth zone D_i, on a seamount j, for a size class k in terms of the subpopulations of zones D_i and D_{i-1} on the higher-level seamount $j-1$. This is expressed as follows:

$$X_{i,j,k} = pX_{i,j-1,k} + (1-p)X_{i-1,j-1,k} \, . \qquad (3)$$

Specifically, if $p=0$, CPUE is distributed solely according to the depth of the top of the seamount and if $p=1$, it is distributed solely according to the absolute depth. If the parameters λ_o, μ_l, σ_l, μ_d, σ_d, ρ, and p, estimated from a known seamount length-depth distribution are known, it is possible to calculate all the CPUE ($X_{i,j,k}$) values for any seamount j (deeper or shallower), depth zone D_i and size class k. The foregoing seven parameters can be estimated by minimizing the SSE between the CPUE recorded on one of the best sampled seamounts (B or J) and the CPUE estimated by Equation 3. This estimation is performed by a nonlinear regression (SAS, 1988).

Results

Bivariate normal model

Application of a bivariate normal model implies that mean length can be deduced from depth by a linear regression weighted by the CPUE $\bar{x}_l = a x_d + b$ where a and b are constants). The results of this regression for seamounts B and J show mean length and depth to be significantly correlated (Table 2). Consequently, the bivariate normal model can be tested for each of these seamounts.

The parameters of the bivariate normal model were calculated separately for seamounts B and J (Table 3). The determination coefficient,[9] R^2, for seamounts B and J respectively equals 0.87 and 0.93. The residual analysis was carried out to test the fit of the model to the data from the *Humboldt* cruise on seamounts B and J. The results show the residuals are

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[9] $R^2 = \left[\Sigma(\hat{Y}_i - \bar{Y})^2 / \Sigma(Y_i - \bar{Y})^2\right]$ with Y = CPUE.

Table 2

Bivariate normal model: CPUE – weighted linear regression of length of alfonsino, ***Beryx splendens***, on depth.

Seamount	No. of fish measured	Min. depth (m)	Max. depth (m)	ρ	α	H_0: $r = 0$	a	b
B	1,557	516	615	0.549	< 0.0001	rejected	0.063	0.037
J	1,957	606	761	0.486	< 0.0001	rejected	1.251	13.122

ρ = regression coefficient.
α = significance probability of the regression under the null hypothesis that the statistic is zero.
H_0 = null hypothesis i.e. length and depth are independent; if $\alpha < 0.05$, H_0 is rejected.
a and b = parameters of the linear regression.

satisfactory; in particular, the residuals are centered on zero, are not correlated with the length and depth variables, and have a constant variance (Table 4; Fig. 6). These characteristics indicate a good fit of the bivariate normal model to the data as demonstrated by comparison of actual and predicted CPUE (Fig. 4).

Extrapolation of the model to the data not used in the modelling exercise is unsatisfactory because the mean value of the residuals is not centered on zero for the *Fukuju Maru* data and because the residuals are correlated with the length variable for the RV *Alis* data and with the depth variable for the *Hokko Maru* data (Table 4; Fig. 6). This suggests the existence of factors affecting the population's distribution not accounted for by the model.

Recursive model

The parameters of the recursive model were estimated separately for seamounts B and J. The deter-

Table 3

Bivariate normal model: predicted parameters for seamounts B and J. SD=Standard deviation.

	Seamount and number of fish measured			
	B 1,557		J 1,957	
Parameters	Estimation	SD	Estimation	SD
λ	3.66×10^6	0.85×10^6	0.5×10^9	4.5×10^9
μ_l	35.22	0.96	12.0	52.0
μ_d	542.87	14.49	–123.1	1,666.7
σ_l	5.31	1.01	8.8	9.6
σ_d	71.07	17.04	272.5	317.1
ρ^2	0.75	0.10	0.9	0.2

λ=theoretical cumulative CPUE.
μ_l=mean length (cm).
μ_d=mean depth (m).
σ_l=standard deviation of length.
σ_d=standard deviation of depth.
ρ^2=regression coefficient of length on depth.

Table 4

Bivariate normal model: results of analysis of residuals (ε) for fit control and temporal validation of the model for seamounts B and J.

	Cruise	Seamount	No. of fish measured	α_1	$H_0 : \bar{\varepsilon} = 0$	α_2	$H_0 : \rho_1 = 0$	α_3	$H_0 : \rho_2 = 0$
Fit control	*Humboldt*	B	1,557	0.289	not rejected	0.153	not rejected	0.149	not rejected
	Humboldt	J	1,957	0.068	not rejected	0.061	not rejected	0.431	not rejected
Temporal validation	*Hokko Maru*	B	2,840	0.262	not rejected	0.601	not rejected	<0.0001	rejected
	RV *Alis*	B	1,688	0.908	not rejected	0.016	rejected	0.391	not rejected
	Fukuju Maru	J	4,320	0.0002	rejected	0.265	not rejected	0.284	not rejected

$H_0 : \bar{\varepsilon} = 0$. The mean value of the deviations between estimated and observed CPUE is 0. If α_1 is <0.05, H_0 is rejected.
ρ_1= regression coefficient of ε on length.
ρ_2=regression coefficient of ε on depth.
H_0:$\rho_1 = 0$. If α_2 is< 5%, H_0 is rejected.
H_0:$\rho_2 = 0$. If α_3 is < 5%, H_0 is rejected.

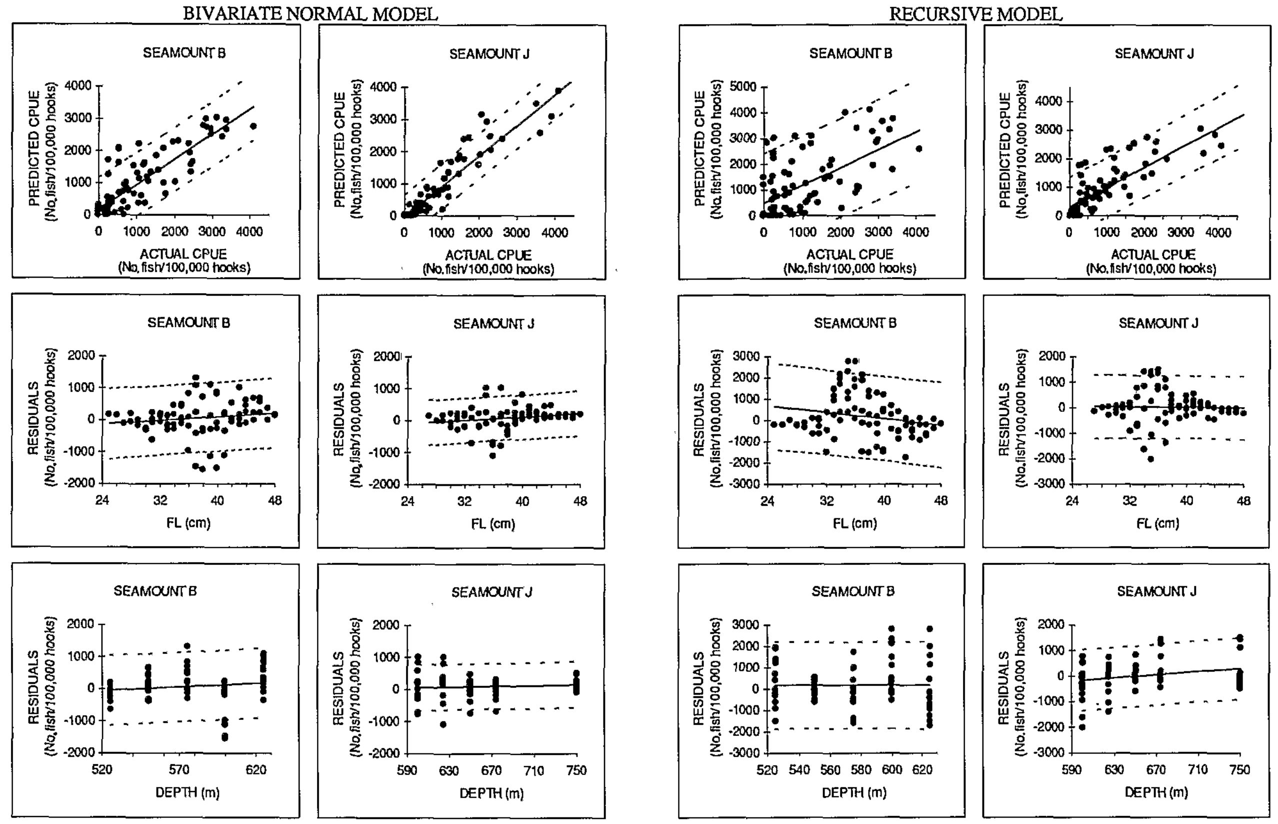

Figure 6

Bivariate normal model and recursive model for seamounts B and J: distribution of predicted CPUE of alfonsino, *Beryx splendens*, in relation to actual CPUE and distributions of residuals in relation to length (cm) and depth (m). Dotted lines delimit the confidence interval at α=0.05.

Table 5

Recursive model: estimated parameters of the distribution of CPUE on the hypothetical original seamount calculated from seamount J data. SD = standard deviation.

Parameters	Estimation	SD
μ_l	22.86	91.3
μ_d	−66.17	499.9
σ_l	5.98	16.5
σ_d	30.27	99.2
ρ^2	0.87	0.70
p	0.09	0.04
λ_o	1.15×10^8	2.33×10^8

μ_l=mean length (cm).
μ_d=mean depth (m).
σ_l=standard deviation of length.
σ_d=standard deviation of depth.
ρ^2=regression coefficient of length on depth.
p=probability that fish will redistribute according to absolute depth.
λ_o=theoretical cumulative CPUE.

mination coefficient, R^2, calculated for seamount J equals 0.82, while for seamount B it equals 0.69. Therefore, the parameters estimated for seamount J were used in the model (Table 5). The residuals resulting from fitting the model to data from the *Humboldt* cruise on seamount J are satisfactory; in particular, they are centered on zero and are not correlated with the studied variables (Table 6; Fig. 6). These features indicate a good fit of the recursive model to the data as demonstrated by comparison of actual and predicted CPUE for seamount J (Fig. 4). It is interesting to note the low value of p (close to 0.1 as shown in Table 5), which indicates that the seamount top depth parameter has greater impact on the length distribution than does the absolute depth parameter.

Spatial validation was carried out for seamount B from the data collected during the *Humboldt* cruise (Table 6). The residuals are centered on zero and not correlated with the length and depth variables. However, since their variance is not constant (Fig. 6) and

Table 6

Recursive model: results of analysis of residuals (ε) for fit control and validation of the model for seamounts B and J.

	Cruise	Seamount	No. of fish measured	α_1	$H_0 : \bar{\varepsilon} = 0$	α_2	$H_0 : \rho_1 = 0$	α_3	$H_0 : \rho_2 = 0$
Fit control	*Humboldt*	J	1,957	0.87	not rejected	0.85	not rejected	0.06	not rejected
Spatial validation	*Humboldt*	B	1,557	0.13	not rejected	0.06	not rejected	0.99	not rejected
Temporal validation	*Hokko Maru*	B	2,840	0.15	not rejected	0.76	not rejected	<0.0001	rejected
	RV *Alis*	B	1,688	0.01	rejected	0.005	rejected	0.35	not rejected
	Fukuju Maru	J	4,301	0.007	rejected	0.67	not rejected	0.08	not rejected

$H_0 : \bar{\varepsilon} = 0$. The mean value of the residuals is 0. If α_1 is <5%, H_0 is rejected.
ρ_1 = regression coefficient of ε on length.
ρ_2 = regression coefficient of ε on depth.
$H_0 : \rho_1 = 0$. If α_2 is <5%, H_0 is rejected.
$H_0 : \rho_2 = 0$. If α_3 is <5%, H_0 is rejected.

since the standard deviations of the parameters are high (Table 5), spatial extrapolation of the model to seamount B is rather crude as demonstrated by comparison of actual and predicted CPUE (Fig. 4).

Temporal validation was carried out on data from the *Fukuju Maru* and RV *Alis* fishing on seamounts B and J (Table 6). It is unsatisfactory because the mean values of the residuals are not centered on zero and the residuals are correlated with the length variable for the RV *Alis* data and with the depth variable for the *Hokko Maru* data (Fig. 6). As with the bivariate normal model, this suggests the existence of factors not accounted for by the model.

Discussion

Alfonsino length structure variation observed over the seamounts of New Caledonia is similar to that noted in Japan[2] and in New Zealand[10] (Massey and Horn, 1990) where it was assigned to age-specific migrations. In Japan, it was noted that alfonsino move south as they grow,[2] young fish predominate over some seamounts and old fish predominate over other seamounts. In New Caledonia, age segregation over the seamounts is so marked that it has been possible to describe it mathematically.

The bivariate normal and recursive models appear to be complementary. The bivariate normal model provides an instantaneous picture of alfonsino population distribution on a given seamount; it provides good CPUE estimates provided a sufficient amount of length and depth data are available. The recursive model takes into account the dynamic nature of the population's distribution as it allows the extrapolation of CPUE obtained for one seamount to seamounts that were not sampled. It allows preliminary population estimation of unexploited stocks. Depending on current economic parameters, the model might be used to indicate the depths at which fishing is most economic. Once a fishery is operational, more refined data will be available, which will enable the bivariate normal model to be applied and stock management parameters defined for each of the seamounts fished.

The poor results obtained for the temporal validation could be due to poor precision of the depth data collected from the longliners *Hokko Maru* and *Fukuju Maru*. Also, neither of the models incorporate a time factor. The data were collected from cruises carried out in different years and in different seasons. Hence, it is unlikely that conditions remained stable, particularly with regard to exploitation history, reproductive behavior, or long-term climatic variations.

Fishing methods and strategies were not modified during the fishing period considered. Therefore, the catches are probably representative of the standing stock of alfonsino within the size limits determined by the selectivity of the fishing gear. Since the daily observation window did not change, vertical trophic migrations would seem unlikely to contribute to the observed variability. With regard to sex as a source of variability, although the mean length of females exceeds that of males[11] (Kotlyar, 1987; Massey and

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[10] Horn, P. L., and B. R. Massey. 1989. Biology and abundance of alfonsino and bluenose off the lower east coast, North Island, New Zealand. N. Z. Fish. Tech. Rep. 15, 31 p.

[11] Lehodey, P. 1994. Les monts sous-marins de Nouvelle-Calédonie et leurs ressources halieutiques. Thèse de doctorat de l'Université Française du Pacifique, 398 p.

Horn, 1990), Humphreys et al. (1984) have shown that sexual dimorphism is not responsible for the existence of different size groups of alfonsino. Marked declines in CPUE are observed in the Southern Hemisphere during summer. This season corresponds to the alfonsino breeding period in New Caledonian waters.[11] The summer decline in catch rate could be due to breeding migrations drawing the fish to spawning grounds that are different from the fishing grounds[2] (Chikuni, 1971) or to changes in vulnerability to the gear owing to seasonal physiological or behavioral changes (Ricker, 1980). Data used to build the models were collected on board the *Humboldt* during the winter season. Data used to validate the models were collected on board *Fukuju Maru* and *Hokko Maru* at the beginning and end of the warm season and during six scientific cruises, five of which were carried out in summer. This suggests that reproductive seasonality might be a factor in the poor temporal validation of the models.

Other sources of temporal variation might be related to the environment. The ocean habitat of alfonsino is not affected by continental influences but is subject to hydrological fluctuations affecting the deep-water masses. Some of these influences are of short period such as internal waves and tidal currents (Eriksen, 1985; Roden, 1987), whereas others recur at longer intervals such as seasonal variations in ocean currents and multi-annual hydroclimatic anomalies of the El Niño Southern Oscillation (ENSO) (Delcroix and Hénin, 1989). Such fluctuations might have an impact on alfonsino stock structure, either at the recruitment stage (survival and dispersal of eggs and larvae) or by modification of the behavior of adults (migrations from one seamount to another). However, it is difficult to demonstrate the effect of these fluctuations on the presence and catchability of fish. It is even more difficult to explain the very large differences in fishery productivity observed between seamounts of identical depth, located only a few dozen miles apart and appearing to have the same hydrological environment. Seafloor topography and bottom type might account for these differences, but other hypotheses can be postulated, some based on the existence of a low-energy hydrothermalism (Rougerie and Wauthy, 1990) and others on a hydrological anomaly called "Taylor's column," which could enhance species sedentarity (Royer, 1978; Genin and Boehlert, 1985; Roden, 1987; Dower et al., 1992; Sime-Ngando et al., 1992). Fluctuations in intensity of this anomaly, or its disappearance, could also be responsible for the variations in productivity observed over time over a given seamount (Boehlert and Genin, 1987). These unknown environmental fluctuations cause problems in the interpretation of results from exploratory and commercial fishing cruises carried out over seamounts. The data collected at a given location constitute an instant picture of a stock whose abundance is likely to vary, irrespective of fishing effort, as a result of unknown environmental variations. In other words, the fertility of the seamounts could vary quite unpredictably over the history of a fishery. Consequently, modelling the distribution of a stock should be confined to a relatively small temporal sampling scale.

Conclusion

The bivariate normal model and the recursive model provide complementary interpretations of length distribution in terms of depth of alfonsino fished on the seamounts of New Caledonia by the bottom longline fishery. They could be useful for the proper management of fisheries over seamounts, where stocks are known to be vulnerable (Sasaki, 1986) because of the limited habitat afforded by seamounts and the slow growth rate of deep-water species. However, it would appear that annual or seasonal factors, in particular those which account for recruitment fluctuations and behavioral changes linked to reproduction, will need to be incorporated into the models before they can be generalized. A better understanding of the functioning of the ecosystems concerned would also assist in establishing the limits of generalization, particularly with regard to depth and area inhabited by alfonsino. These models could possibly be adapted to other deep-water species such as certain snappers and groupers.

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