

Variability of Fish Catches in Different Ecosystems

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ABSTRACT

The effect of the number of years over which catch variability is calculated was determined for different fish species/genus in different FAO subareas (Atlantic, Pacific, Mediterranean) for the 1970-1991 period. Overall, 109 species/subarea catch series, making up more than 40% of the annual world marine catch, were analyzed. The results indicated that for the vast majority of the catch series, variability increases with the length of time over which it is calculated. The increasing variability with time indicates that most of the species/subarea catches show long-term trends and, hence, 'reddened' spectra. As a result, fishery managers and scientists are confronted with variables that do not explore quickly their size limits but rather wander and reach new extreme values continually. Such a pattern suggests that there is not any equilibrium yield, though the latter is at the basis of most models presently used for fisheries management. The results also indicated that between-species/genus variability is a function of species' life history. Moreover, the results revealed that within-species/genus, variability is higher in the four major upwelling areas of the world, especially in the Peruvian one, and lower in the Mediterranean Sea. Within-species/genus, differences in variability (i.e., spatial) are found to be a function of the community/ecosystem characteristics of the marine region of concern.

RÉSUMÉ

La variabilité des captures en fonction du temps (nombre d'années considérées) a été déterminée pour différentes espèces/genres de poissons dans différentes sous-zones FAO (Atlantique, Pacifique, Méditerranée) pour la période 1970-1991. Globalement, 109 séries de capture par espèce/sous-zone, réalisant plus de 40 % des captures marines annuelles mondiales, furent analysées. Les résultats indiquent que pour la grande majorité des séries de capture la variabilité s'accroît avec la période de temps considérée. La variabilité croissante avec le temps indique que la plupart des captures d'espèces/sous-zones présentent une tendance à long terme et, par conséquent, un spectre « rouge ». Un premier résultat est que les aménagés et les scientifiques sont confrontés à des variables qui n'explorent pas rapidement leur limite extrême, mais au contraire se promènent entre des bornes sans cesse fluctuantes. Un tel pattern suggère qu'il n'existe pas d'équilibre, qui constitue cependant la notion fondamentale de la plupart des modèles présentés en aménagement des pêches. Les résultats indiquent aussi que pour les mêmes espèces/genres, la variabilité est plus grande dans les quatre grandes zones d'upwelling mondiales, principalement au Pérou ; et plus faible en Méditerranée. Pour les mêmes espèces/genres, les différences observées dans la variabilité (c'est-à-dire spatiale) apparaissent comme une fonction des caractéristiques de la communauté/écosystème de la région marine considérée.

INTRODUCTION

Pimm and Redfearn (1988) showed that the variability of a simulated 'red' population density series, formed by summing sine waves with random phases and amplitudes that increase linearly with period, differs greatly from the variability of a simulated 'white' population density series, formed by choosing densities randomly with uniform probability over the same range as those densities in the 'red' model. Pimm and Redfearn (1988) showed that for the 'red' series, variability increases with an increase in the length of period over which variability is estimated. Consequently, Pimm and Redfearn (1988) estimated the standard deviation of logged catch (SDL) of the abundance of 42 farmland bird species, 32 woodland bird species, 22 other bird and mammal species and four insect species over different time periods (i.e., 2, 4, 8 and 16 years for the first two groups and 2, 4, 8, 16, 32 and 50 years for the last two groups). They found that SDL increases with the length of time over which it is calculated for all groups with the exception of insects for which SDL leveled off at very long periods (>8 years). Fisheries catches are generally highly variable. Caddy and Gulland (1983)

distinguished empirically four classes of fisheries in terms of pattern of their species catch variability: steady-state, cyclical, irregular and spasmodic fisheries and similar classification was provided by Kawasaki (1983). In addition, it is well known that the major upwelling areas of the world sustain some of the most productive and irregular fisheries (Bakun, 1985). Yet, these and related issues of fish catch variability have not so far been approached quantitatively.

In the present study, the effect of the number of years over which catch variability is calculated as well as between-species and within-species variability were determined for a variety of species in different FAO subareas (Atlantic, Pacific, Mediterranean). The following species/genus were considered: *Engraulis* spp., *Trachurus* spp., *Sardinops* spp., *Scomber japonicus* and *Merluccius* spp. (the main species found in the four major upwelling areas of the world: Bakun, 1985) as well as *Sardinella* spp., *Sardina pilchardus*, *Mallotus villosus*, *Scomber* spp., *Clupea* spp., *Micromesistius poutassou*, *Plurionectes platessa*, *Hippoglossoides platessoides*, *Gadus* spp., *Theragra chalcogramma*, *Thunnus albacares*, *Katsuwonus pelamis*, *Xiphias gladius* and Elasmobranchii. The above mentioned species make up more than 40% of the annual world marine catch.

1. MATERIAL AND METHODS

Data was extracted using FISHSTAT-PC (FAO Fisheries department, Release 1993A, April 1993). Overall, 109 species per FAO-subarea catch records, referring to the 1970-1991 period, were analyzed. Catch records of species/subarea including many zero values were not taken into account. Scientific names of species are according to FAO Bulletins. The methodology used has been described by Pimm and Redfearn (1988). The measure of variability (standard deviation of logged catch: SDL) and time scales over which SDL was calculated were both selected such that the results presented here could be directly comparable with those of Pimm and Redfearn (1988). For all species/subarea catch records analyzed, SDL was calculated over 2, 4, 8, 16 and 22 years (i.e., the maximum period available) and calculations refer to nested data (i.e., first two years, first four years, etc.).

2. RESULTS

The results indicated that for the majority of species/subarea catches analyzed, variability increases with the length of time over which it is calculated (Tables 1 and 2; Fig. 1). Hence, the slopes of the regressions between SDL and time period over which SDL was calculated, were significantly ($P < 0.05$) different from zero and positive for 63 (58%) species/subarea catches when only 2, 4, 8 and 16 years were considered (i.e., 4-point regressions) as well as when regressions also included SDL calculated over the total period (i.e., 22 years, 5-point regressions; Table 1). Overall, slope values were negative for five species/subarea catch series (4-point regressions: *Katsuwonus pelamis* in SW and SE Pacific and *Xiphias gladius* in SE Pacific; 5-point regressions: *Katsuwonus pelamis pelamis* in SW and SE Pacific and *Xiphias gladius* in SE Pacific; 5-point regressions: *Katsuwonus pelamis* in SW Pacific and *Thunnus albacares* in NW Pacific: Table 1). The arithmetic values of the slopes (excluding the negative ones) ranged from 0.0024 to 0.0590, for the 4-point regressions, and from 0.0016 to 0.1390, for the 5-point regressions (Table 1).

Species	FAO Subarea	(2, 4, 8, 16)		(2,4,6, 8, 16, 22)		min	max	mean	max/min
		r	b	r	b				
<i>Engraulis anchoita</i>	Atlantic, Southwest	0.46	-	0.32	-	10137	41100	20565	4.1
<i>Engraulis capensis</i>	Atlantic, Southeast	0.73	-	0.89	0.006	167657	969401	436983	5.8
<i>Engraulis encrasicolus</i>	Atlantic, Northeast	0.93	0.015	0.91	0.011	5423	59674	25985	11
<i>Engraulis encrasicolus</i>	Atlantic, Eastern central	0.95	0.007	0.96	0.011	22000	347247	97539	15.8
<i>Engraulis encrasicolus</i>	Mediterranean	0.94	0.0032	0.96	0.0028	63988	152413	98991	2.38
<i>Engraulis japonicus</i>	Pacific, Northwest	0.94	0.004	0.95	0.003	296428	500614	381820	1.7
<i>Engraulis mordax</i>	Pacific, Eastern central	0.92	0.008	0.95	0.012	5993	424397	170652	70.8
<i>Engraulis ringens</i>	Pacific, Southeast	0.88	0.031	0.82	-	93654	1,3E+07	3423358	139.4
<i>Merluccius bilinearis</i>	Atlantic, Northwest	0.95	0.016	0.88	0.011	53332	434900	139013	8.2
<i>M. capensis, M. paradox</i>	Atlantic, Southwest	0.96	0.009	0.96	0.007	229547	1122000	566920	4.9
<i>Merluccius gayi</i>	Pacific, Southeast	0.91	0.015	0.88	0.011	31260	382439	133845	12.2
<i>Merluccius hubbsi</i>	Atlantic, Southwest	0.93	0.013	0.89	0.009	108100	521312	314790	4.8
<i>Merluccius merluccius</i>	Atlantic, Eastern Central	0.52	-	0.41	-	2900	13810	8172	4.8
<i>Merluccius merluccius</i>	Atlantic, Northeast	0.49	-	0.62	-	49555	117100	76953	2.4
<i>Merluccius merluccius</i>	Mediterranean	0.95	0.007	0.95	0.057	16809	47985	30213	2.85
<i>Merluccius productus</i>	Pacific, Northeast	0.96	0.009	0.98	0.009	31312	297966	153365	9.5
<i>Merluccius senegalensis</i>	Atlantic, Eastern Central	0.71	-	0.69	-	8425	102241	36239	12.1
<i>Sardina pilchardus</i>	Atlantic, Eastern Cenral	0.57	-	0.65	-	319500	1118084	636149	3.5
<i>Sardina pilchardus</i>	Atlantic, Northeast	0.47	-	0.42	-	136014	236370	182921	1.7
<i>Sardina pilchardus</i>	Mediterranean	0.99	0.0044	0.98	0.0035	148801	284411	213820	1.91
<i>Sardinella aurita</i>	Atlantic, Eastern Central	0.93	0.0198	0.95	0.0176	18800	328035	129296	17.4
<i>Sardinella aurita</i>	Atlantic, Western Central	0.81	-	0.89	0.0042	24344	86585	53274	3.6
<i>Sardinella brasiliensis</i>	Atlantic, Southwest	0.61	-	0.86	-	32081	228000	125822	7.1
<i>Sardinella gibbosa</i>	Pacific, Western Central	0.94	0.014	0.92	0.0103	24000	127890	79638	5.3
<i>Sardinella lemuru</i>	Pacific, Western Central	0.96	0.0175	0.94	0.0131	12500	107160	51936	8.6
<i>Sardinella maderensis</i>	Atlantic, Eastern Central	0.94	0.0341	0.96	0.0301	194	38938	11503	200.7
<i>Sardinops caeruleus</i>	Pacific, Eastern Central	1	0.0197	0.98	0.02	35500	509248	268553	14.3
<i>Sardinops melanostictus</i>	Pacific, Northwest	0.93	0.0324	0.87	-	16900	5428922	2816178	321.2
<i>Sardinops ocellatus</i>	Atlantic, Southeast	0.93	0.022	0.92	0.0171	62981	677093	265247	10.8
<i>Sardinops sagax</i>	Pacific, Southeast	0.92	0.0496	0.86	-	11400	6509301	2834290	571
<i>Scomber japonicus</i>	Pacific, Northwest	0.98	0.004	0.97	0.006	611744	2238781	1393759	3.7
<i>Scomber japonicus</i>	Atlantic, Southeast	0.97	0.013	0.96	0.011	16352	201556	57631	12.3
<i>Scomber japonicus</i>	Atlantic, Northeast	0.98	0.017	0.9	0.011	1749	39000	10484	22.3
<i>Scomber japonicus</i>	Pacific, Eastern Central	0.99	0.059	0.95	0.043	200	77986	30338	389.9
<i>Scomber japonicus</i>	Atlantic, Southwest	1	0.018	0.94	0.012	4724	71968	18611	15.2
<i>Scomber japonicus</i>	Pacific, Western Central	0.98	0.018	0.95	0.014	534	4287	1213	8
<i>Scomber japonicus</i>	Atlantic, Western Central	0.23	-	0.1	-	113	1200	497	10.6
<i>Scomber japonicus</i>	Atlantic, Eastern Central	0.9	0.007	0.94	0.006	87173	326193	179894	3.7
<i>Scomber japonicus</i>	Pacific, Southeast	0.87	0.022	0.76	-	51800	835958	313876	16.1
<i>Scomber</i> spp.	Mediterranean	0.98	0.0078	0.98	0.0068	9740	26468	17112	2.7
<i>Trachurus capensis</i>	Atlantic, Southeast	0.82	-	0.7	-	64900	686943	446810	10.6
<i>Trachurus japonicus</i>	Pacific, Northwest	0.89	0.008	0.89	0.006	56742	283400	161632	5
<i>Trachurus murphyi</i>	Pacific, Southeast	0.98	0.03	0.97	0.024	108700	3852928	1606507	35.4
<i>Trachurus picturatus</i>	Atlantic, Southwest	0.72	-	0.7	-	81	2004	673	24.7
<i>Trachurus symmetricus</i>	Pacific, Eastern Central	0.61	-	0.82	-	1745	49957	17292	28.6

Table 1 (to be continued on next two pages): Minimum, maximum, mean and (maximum/minimum) ratio values of the 107 species/FAO-subarea catches over the 1970-1991 period examined in the present study together with the correlation coefficient (r) and the slope (b) values of the regressions of SDL versus the length of period for 4 data points (i.e., 2, 4, 8, and 16 years) and 5 data points (i.e., 2, 4, 8, 16 and 22 years). Slopes not shown were not significantly different from 0 (P>0.05).

Species	FAO Subarea	(2, 4, 8, 16)		(2,4,6, 8, 16, 22)		min	max	mean	max/min
		r	b	r	b				
<i>Trachurus trachurus</i>	Atlantic, Eastern Central	0.7	-	0.57	-	0	3118	846	-
<i>Trachurus trachurus</i>	Atlantic, Northeast	0.93	0.008	0.1	0.006	136721	440292	258597	3.2
<i>Trachurus trecae</i>	Atlantic, Southeast	0.32	-	0.35	-	31298	378255	135484	12.1
<i>Trachurus</i> spp.	Mediterranean	0.93	0.0055	0.88	0.0039	25998	49438	34570	1.9
<i>Clupea harengus</i>	Atlantic, Northwest	0.95	0.0122	0.85	-	165720	849100	342812	5.1
<i>Clupea harengus</i>	Atlantic, Northeast	0.91	0.0092	0.85	-	632515	1494100	1088537	2.4
<i>Clupea pallasii</i>	Pacific, Northwest	0.99	0.0177	0.96	0.0132	86799	525800	252822	6.1
<i>Clupea pallasii</i>	Pacific, Northeast	0.74	-	0.76	-	65903	155800	92668	2.4
<i>Melilotus villosus</i>	Atlantic, Northwest	0.39	-	0.22	-	5900	367215	118687	62.2
<i>Melilotus villosus</i>	Atlantic, Northeast	0.78	-	0.89	0.0023	777112	3773808	1969124	4.9
<i>Melilotus villosus</i>	Pacific, Northwest	0.97	0.02258	0.98	0.0023	1039	38984	8062	37.5
<i>Miromesistius poutassou</i>	Atlantic, Northeast	0.98	0.032	0.93	0.0227	30512	1106448	471433	36.3
<i>Pleuronectes platessa</i>	Atlantic, Northeast	0.99	0.003	0.95	0.0022	133750	203308	174231	1.5
<i>Hippoglossoides platessoides</i>	Atlantic, Northwest	0.91	0.0027	0.96	0.0036	42887	117400	84971	2.7
<i>Gadus morhua</i>	Atlantic, Northwest	0.73	-	0.65	-	422625	1161500	680057	2.7
<i>Gadus morhua</i>	Atlantic, Northeast	0.95	0.0024	0.96	0.0034	916208	2019978	1538198	2.2
<i>Gadus macrocephalus</i>	Pacific, Northwest	0.96	0.0086	0.98	0.0079	60218	271591	134256	4.5
<i>Gadus macrocephalus</i>	Pacific, Northeast	0.55	-	0.75	-	38800	262881	126186	6.8
<i>Theragra chalcogramma</i>	Pacific, Northwest	0.28	-	0.37	-	2E+06	5153770	3797126	2.6
<i>Theragra chalcogramma</i>	Pacific, Northeast	0.5	-	0.6	-	679022	1714473	1175066	2.5
<i>Kaisuwonus pelamis</i>	Atlantic, Northeast	0.92	-0.0133	0.87	-	124	13789	3395	111.2
<i>Kaisuwonus pelamis</i>	Atlantic, Western Central	0.99	0.0233	0.92	0.0157	1673	20875	7053	12.5
<i>Kaisuwonus pelamis</i>	Atlantic, Eastern Central	0.79	-	0.88	0.0016	40786	172223	87121	4.2
<i>Kaisuwonus pelamis</i>	Atlantic, Southwest	1	0.0529	0.97	0.0408	87	25198	10243	289.6
<i>Kaisuwonus pelamis</i>	Atlantic, Southeast	0.97	0.0232	0.98	0.0204	109	4472	1712	41
<i>Kaisuwonus pelamis</i>	Indian Ocean, Western	0.97	0.012	0.97	0.0157	25329	218952	81881	8.6
<i>Kaisuwonus pelamis</i>	Indian Ocean, Eastern	0.95	0.0147	0.95	0.012	2300	19348	9316	8.4
<i>Kaisuwonus pelamis</i>	Pacific, Northwest	0.2	-	0.38	-	99905	226955	148691	2.3
<i>Kaisuwonus pelamis</i>	Pacific, Western Central	0.95	0.0071	0.98	0.0073	90450	859307	381378	9.5
<i>Kaisuwonus pelamis</i>	Pacific, Eastern Central	0.84	-	0.75	-	32540	141815	81856	4.4
<i>Kaisuwonus pelamis</i>	Pacific, Southwest	0.98	-0.0399	0.99	-0.036	0	17932	6048	-
<i>Kaisuwonus pelamis</i>	Pacific, Southeast	0.7	-	0.72	-	9870	47361	25985	4.8
<i>Thunnus albacares</i>	Atlantic, Western Central	0.99	0.0163	0.88	0.008	5350	31977	15895	6
<i>Thunnus albacares</i>	Atlantic, Eastern Central	0.82	-	0.63	-	53581	148111	104457	2.8
<i>Thunnus albacares</i>	Atlantic, Southwest	0.83	-	0.72	-	915	5209	2895	5.7
<i>Thunnus albacares</i>	Atlantic, Southeast	0.86	-	0.78	-	1468	7648	2959	5.2
<i>Thunnus albacares</i>	Indian Ocean, Western	0.99	0.0134	0.99	0.0109	21610	166253	64221	7.7
<i>Thunnus albacares</i>	Indian Ocean, Eastern	0.83	-	0.73	-	3292	18181	10316	5.5
<i>Thunnus albacares</i>	Pacific, Northwest	0.76	-	0.9	-0.0013	11343	45304	32038	4
<i>Thunnus albacares</i>	Pacific, Western Central	0.99	0.0095	0.95	0.0058	59000	356755	169720	6
<i>Thunnus albacares</i>	Pacific, Eastern Central	0.2	-	0.83	-	109250	282595	195137	2.6
<i>Thunnus albacares</i>	Pacific, Southwest	0.43	-	0.45	-	940	16233	5622	17.3
<i>Thunnus albacares</i>	Pacific, Southeast	0.69	-	0.9	0.0049	18260	88176	37153	4.8
<i>Xipbias gladius</i>	Atlantic, Northwest	0.82	-	0.83	-	401	5856	2987	14.6
<i>Xipbias gladius</i>	Atlantic, Northeast	0.97	0.0085	0.99	0.0089	2612	12138	5189	4.6
<i>Xipbias gladius</i>	Atlantic, Western Central	0.94	0.0156	0.93	0.012	284	5212	1966	18.4
<i>Xipbias gladius</i>	Atlantic, Eastern Central	0.99	0.0079	0.99	0.0072	1294	4354	2261	3.4
<i>Xipbias gladius</i>	Atlantic, Southwest	0.82	-	0.52	-	629	6403	2134	10.2

Table 1 (continuation)

Species	FAO Subarea	(2, 4, 8, 16)		(2,4,6, 8, 16, 22)		min	max	mean	max/min
		r	b	r	b				
<i>Xiphias gladius</i>	Atlantic, Southeast	0.92	0.0106	0.96	0.139	317	9308	2145	29.4
<i>Xiphias gladius</i>	Pacific, Northwest	0.73	-	0.63	-	5574	10839	8483	1.9
<i>Xiphias gladius</i>	Pacific, Western Central	0.91	0.0057	0.94	0.0051	1931	4997	3281	2.6
<i>Xiphias gladius</i>	Pacific, Eastern Central	0.77	-	0.54	-	2697	8463	5474	3.1
<i>Xiphias gladius</i>	Pacific, Southwest	0.81	-	0.75	-	383	1865	1091	4.9
<i>Xiphias gladius</i>	Pacific, Southeast	0.96	-0.0131	0.34	-	500	8403	2177	16.8
<i>Elasmobranchii</i>	Atlantic, Northeast	0.91	0.0286	0.93	0.023	895	14200	6183	15.9
<i>Elasmobranchii</i>	Atlantic, Western Central	0.99	0.0116	0.98	0.0097	3100	17642	9229	5.7
<i>Elasmobranchii</i>	Atlantic, Eastern Central	0.86	-	0.58	-	14544	32942	23876	2.3
<i>Elasmobranchii</i>	Atlantic, Southwest	0.71	-	0.71	-	2300	29864	16635	13
<i>Elasmobranchii</i>	Atlantic, Southeast	0.92	0.0149	0.88	0.0102	1230	9538	3683	7.8
<i>Elasmobranchii</i>	Pacific, Northwest	0.87	-	0.92	0.0023	54834	96888	80602	1.8
<i>Elasmobranchii</i>	Pacific, Western Central	1	0.0066	1	0.0065	19900	53317	33033	2.7
<i>Elasmobranchii</i>	Pacific, Eastern Central	0.92	0.0062	0.92	0.0048	9430	22218	15813	2.4
<i>Elasmobranchii</i>	Pacific, Southwest	0.5	-	0.83	-	1800	7601	3860	4.2
<i>Elasmobranchii</i>	Pacific, Southeast	0.93	0.0076	0.9	0.0088	300	3255	1652	10.9

Table 1 (concluded).

For the different species/genus considered in the present study, the percentage of catch/subarea for which SDL increases over the different time periods examined ranged between 55% and 100%, with the following exceptions: (a) *Merluccius* spp., *Sardina pilchardus*, *Sardinops* spp., *Scomber japonicus* and *Clupea* spp. for the 16- versus 22-year comparison, for which the percentage ranged between 0 and 44%; and (b) *Trachurus* spp. and *Mallotus villosus* for the 8- versus 16-year comparison, for which the percentage was 38 and 33%, respectively (Table 2). Overall, 78% of the total species/subarea catch records showed an increase in SDL from 2 versus 4 years, 75% from 4 versus 8 years, 76% from 8 versus 16 years and 57% from 16 versus 22 years (Table 2). The percentages for the successive changes in SDL in the first three time periods were generally higher for the relatively small-sized pelagic and demersal species (*Engraulis* spp., *Sardinops* spp., *Sardinella* spp., *Sardina pilchardus*, *Mallotus villosus*, *Clupea* spp., *Scomber* spp., *Trachurus* spp., *Merluccius* spp. and 'other') than for the relatively large-sized pelagic and demersal ones (*Gadus* spp., *Thunnus albacares*, *Katsuwonus pelamis*, *Xiphias gladius* and *Elasmobranchii*). The opposite was true of the percentages of catch records showing changes in SDL from 16 to 22 years (Table 2).

All regressions between the mean SDL of the catches of each genus/species over the different subareas and time period over which SDL was calculated, had positive slopes, significantly ($P < 0.05$) different from zero with the only exception of *Mallotus villosus* (Fig. 1). However, when the catch record of *Mallotus villosus* in the NE Atlantic was extended back to 1918 (72 years; data from Stergiou (1984)), SDL was found to increase linearly with time over all time scales (Fig. 1). When the logged slopes of the 4-point mean-SDL/time regressions per species/genus (shown in Fig. 1) were regressed against the logged maximum body size per species/genus (Fig. 2), the resulting regression had a negative slope significantly ($P < 0.05$) different from zero.

The mean slope of all 4-point SDL-time regressions (Table 1) was higher in the four major subtropical eastern boundary regions (FAO subareas: eastern-central and SE Pacific and Atlantic, corresponding roughly to California, Peru, Canary and Benguela upwelling regions) than in non-upwelling ones (0.0198 ± 0.0031 and 0.0141 ± 0.0017 , respectively) but the difference was not significant (t-test, $P > 0.05$).

Species	N	2	4	8	16	Size Category
		versus 4	versus 8	versus 16	versus 22	
Number						
<i>Sardinops</i>	4	3	4	4	1	small
<i>Scomber japonicus</i>	9	9	7	9	4	small
<i>Trachurus</i>	8	6	8	3	5	small
<i>Sardinella</i>	6	5	5	4	6	small
<i>Sardina pilchardus</i>	3	2	2	2	1	small
<i>Clupea</i>	4	3	3	4	0	small
<i>Engraulis</i>	8	6	6	8	5	small
<i>Merluccius</i>	9	6	6	7	3	small
<i>Mallotus villosus</i>	3	3	3	1	2	small
Other ^{a)}	7	6	7	7	5	small
<i>Thunnus albacares</i>	11	11	7	8	6	large
<i>Xiphias gladius</i>	11	6	6	6	7	large
<i>Gadus</i>	4	4	3	3	3	large
<i>Katsuwonus pelamis</i>	12	9	9	8	8	large
<i>Elasmobranchii</i>	10	6	6	9	6	large
Percentages						
<i>Sardinops</i>	—	75	100	100	25	small
<i>Scomber japonicus</i>	—	100	78	100	44	small
<i>Trachurus</i>	—	75	100	38	63	small
<i>Sardinella</i>	—	83	83	67	100	small
<i>Sardina pilchardus</i>	—	67	67	67	33	small
<i>Clupea</i>	—	75	75	100	0	small
<i>Engraulis</i>	—	75	75	100	63	small
<i>Merluccius</i>	—	67	67	78	33	small
<i>Mallotus villosus</i>	—	100	100	33	67	small
Other*	—	86	100	100	71	small
<i>Thunnus albacares</i>	—	100	64	73	55	large
<i>Xiphias gladius</i>	—	55	55	55	64	large
<i>Gadus</i>	—	100	75	75	75	large
<i>Katsuwonus pelamis</i>	—	75	75	67	67	large
<i>Elasmobranchii</i>	—	60	60	90	60	large
Total	109	85	82	83	62	both
% of Total	100	78	75	76	57	both
Total 1	61	49	51	49	32	small
%	—	80	84	80	52	small
Total 2	48	36	31	34	30	large
%	—	75	65	71	63	large

a) consisting of *Micromesistius poutassou*, *Pleuronectes platessa*, *Hippoglossoides platessoides* and *Theragra chalcogramma*.

Table 2: Number and percentages of species/FAO-subarea catches for which SDL increases were examined over different time periods.

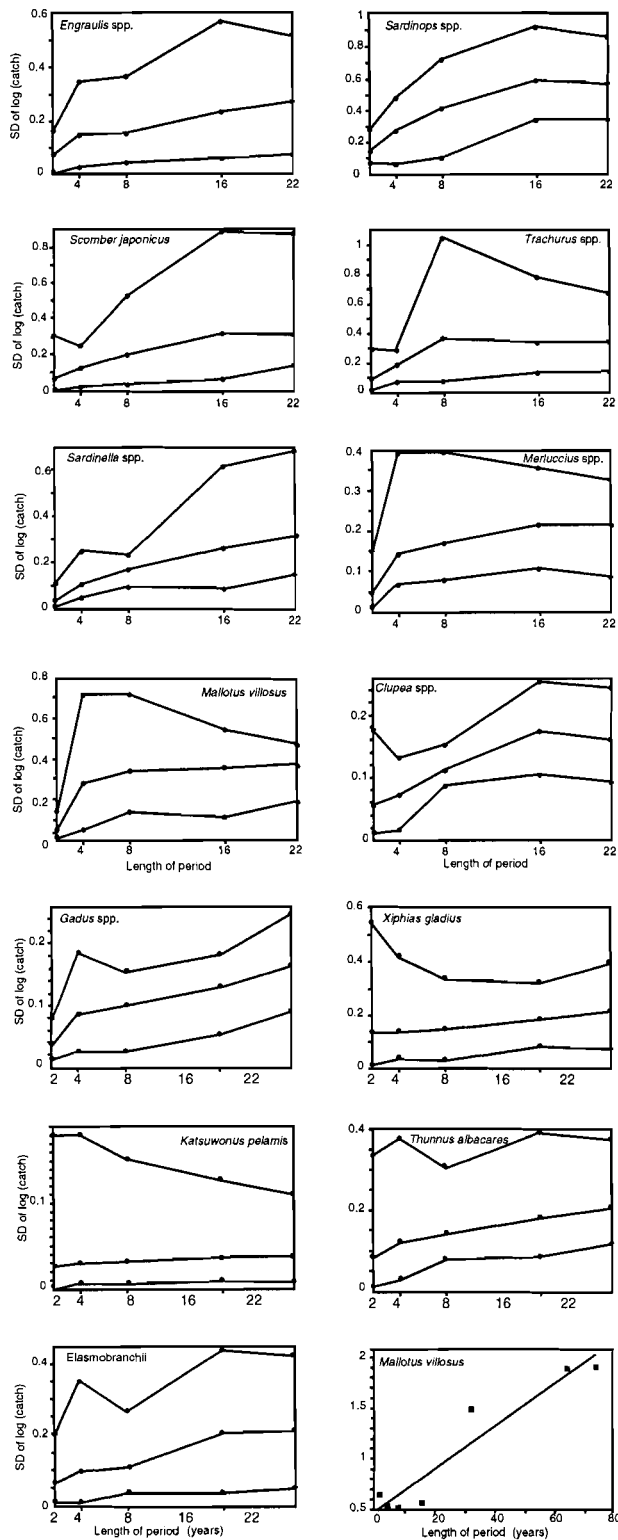


Fig. 1: Variability of catches (standard deviation of logged catches, SDL) versus the number of years over which SDL was calculated for a variety of fish species/ genus/ groups. On each graph, the middle line joins the mean SDL values among the different species over all subareas considered whereas the top and bottom lines join the maximum and minimum values, respectively. With the exception of *Mallotus villosus*, all regressions, between mean SDL and length of the time period over which SDL was calculated, are significant at $P < 0.05$ ($n=4$; 2, 4, 8 and 16 years). The last graph (bottom right) refers to the catches of *Mallotus villosus* in the NE Atlantic for the period 1918-1991 (data from Stergiou (1984)) and SDL is plotted against 2, 4, 8, 16, 32, 64 and 72 years; the slope of the regression line ($=0.0216$) is significantly ($P < 0.05$) different from zero.

Fig. 2: Regression between the logged slopes of the 4-point SDL-time regressions (graphs shown in Fig. 1) and the logged maximum body length in cm (maximum body length values taken from Whitehead et al. (1984)).

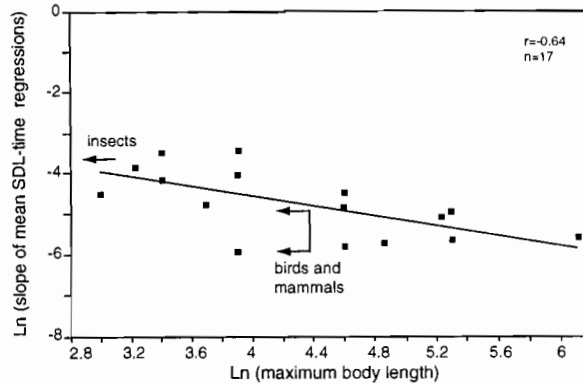
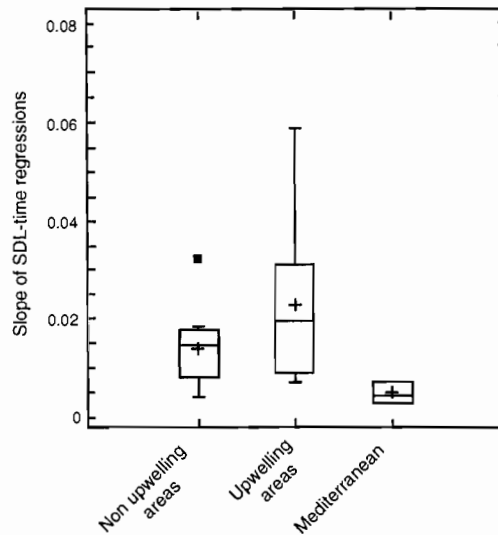


Fig. 3: Box-Whiskers plots of the slopes of the SDL-time regressions of all species considered in the present study in three different ecosystems: non-upwelling areas (NE, SE, western-central, NW Atlantic and Pacific); major upwelling areas (FAO subareas: eastern-central and SE Pacific and Atlantic, corresponding roughly to California, Peru, Canary and Benguela upwelling regions); and Mediterranean Sea. The central box encloses the middle 50% of the values, the horizontal line inside the box shows the median value of the data, the cross inside the box shows the mean value of the data, and the vertical lines extending from each end of the box (i.e., whiskers) enclose 75% of the values; one outlier is marked by a black square.



In addition, the values of the slopes of the SDL-time regressions for *Engraulis encrasicolus*, *Sardina pilchardus*, *Trachurus* spp., *Scomber* spp. and *Merluccius merluccius* in the Mediterranean Sea were by one order of magnitude smaller than the corresponding ones in the Atlantic and Pacific Oceans (Table 1). The mean value of the slopes of all 4-point SDL-time regressions differed significantly (ANOVA, $P < 0.05$) between regions attaining the highest value for all major upwelling regions combined and lower ones for the Mediterranean Sea (see Fig. 3). In addition, when the major upwelling species as well as their non-upwelling counterparts thriving in similar latitudinal zones were considered alone (i.e., *Engraulis* spp., *Trachurus* spp., *Sardinops* spp., *Scomber* spp., *Merluccius* spp., *Sardinella* spp. and *Sardina pilchardus*), the mean value of the slopes of the above mentioned regressions differed significantly (ANOVA, $P < 0.05$) between regions in the following order: Peruvian > remaining upwelling areas > non-upwelling Atlantic and Pacific areas > Mediterranean Sea (see also Fig. 4). In addition, in both cases, the minimum, maximum and median slope values displayed differences similar to those of the mean slopes (Fig. 3 and 4).

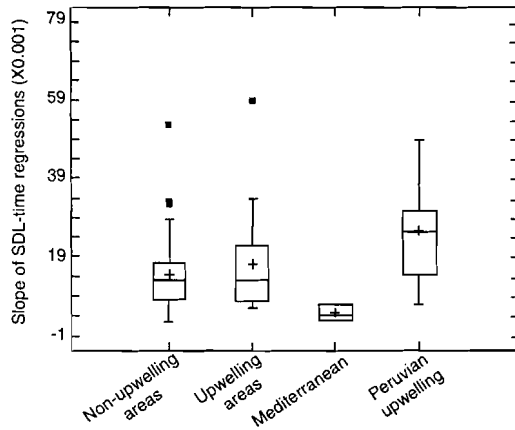


Fig. 4: Box-Whiskers plots of the slopes of the SDL-time regressions for the major upwelling fish species as well as their non-upwelling counterparts occurring in similar latitudinal zones (i.e., *Engraulis* spp., *Trachurus* spp., *Sardinops* spp., *Scomber* spp., *Merluccius* spp., *Sardinella* spp. and *Sardina pilchardus*), in four different ecosystems: non-upwelling areas (NE, SE, western-central, NW Atlantic and Pacific); Peruvian upwelling (FAO subarea: SE Pacific); remaining major upwelling areas (FAO subareas: eastern-central Pacific and eastern-central and SE Atlantic, corresponding roughly to California, Canary and Benguela upwelling regions); and Mediterranean.

DISCUSSION

The results indicated that for the majority of species/subarea catches analyzed, variability increases with the length of time over which it is calculated. The increasing variability with time indicates that most of the species/subarea catches examined here exhibit long-term trends and, hence, 'reddened' spectra. In other words, fishery managers and scientists are confronted with variables that do not explore quickly their size limits but rather wander and reach new extremes. The results have important implications which were stressed by Pimm and Redfearn (1988) for terrestrial populations and are directly applicable to fisheries. Such a pattern in fish catch variability suggests that there is no 'equilibrium yield', even though they are assumed by most models presently used for fisheries management; steady yield seems to be the exception rather than the rule (Caddy and Sharp, 1986; Hilborn and Walters, 1992). Yet, long-term trends and cycles in commercial catches can be incorporated into various fishery models (Taylor and Prochaska, 1984).

The negative relationship between variability and body size most probably indicates that between-species/genus variability is a function of species' life history (i.e., trophic position in the food web, natural rate of population increase and natural mortality, all of which are size-related processes (Kawasaki, 1983; Caddy and Sharp, 1986; Pimm, 1991). This is consistent with the results of Warner *et al.* (1994) who, after estimating the Hurst exponent for a variety of terrestrial and aquatic population series, found a significant ($P < 0.003$) negative correlation between the values of the Hurst exponent and species' body size. It is worthy to point out that the degree of risk accepted by fishery managers tend to be generally higher for small-sized rather than large-sized fish species.

It is interesting to compare the results presented here with those of Pimm and Redfearn (1988). The slope values of the 4-point SDL-time regressions of the 94 farmland and woodland bird and mammal species (estimated by the present author from Pimm and Redfearn's (1988) data) ranged between 0.003 (logged value = -5.81) and 0.008 (logged value = -4.83) whereas the slope value of the four insect species was 0.026 (logged value = -3.65) (Fig. 2), a fact indicating that the former are ecologically equivalent, in terms of variability, to small-sized fish and the latter to large-sized ones.

Catch variability differs between regions in the following order: Peruvian upwelling > other upwelling areas > non upwelling Atlantic and Pacific areas > Mediterranean. This suggests that in the case of within-species/genus, spatial differences in variability are a function of the community/ecosystem characteristics of the marine region in concern, such as the trophic potential and complexity of the food web (i.e., primary production and number of trophic levels) and the environmental dynamics affecting community characteristics. Indeed, the four major upwelling ecosystems are generally controlled by similar environmental dynamics and inhabited by similar communities of exploited fisheries stocks that most probably have adapted to similar environmental/community characteristics (Bakun, 1985, 1990). Yet, the Peruvian upwelling region is characterized, when compared with the remaining major upwelling areas, by: (a) a longer effective upwelling period, i.e., more or less throughout the year; (b) more intense effect of ENSO events (Mann and Lazier, 1991); and (c) the highest fishery catch densities (Cury, 1995; Faure and Cury, this vol.). In contrast, there is a pronounced oligotrophy in the surface waters of the Mediterranean Sea, especially so in its eastern part (Aegean and Levantine Seas) because of the low nutrient concentration in the trophogenic layer. The latter is attributed to: (a) the lack of significant upwelling areas, resulting to upwelling of 'new' nutrients from deep waters in the euphotic zone, the key to high biological productivity; (b) the relatively small amounts of discharge from land; and (c) the fact that in the Mediterranean Sea, where total evaporation exceeds precipitation and river runoff (Hopkins, 1978), the conservation of mass and salinity is maintained by the balance of a two-layer flow through the Strait of Gibraltar: surface, nutrient-poor Atlantic waters inflow in the upper layer whereas Mediterranean deeper waters outflow in the lower layer. In addition, in the Mediterranean Sea, especially in the southern part, the importance of picoplankton increases, a fact which presumably increases the number of trophic levels and, hence, may limit the potential production at higher trophic levels (Azov, 1991). As a result of this, the Mediterranean Sea is characterized by a low fish catch density (1.4 t/km² of continental shelf), which is many times lower than that in upwelling as well as some other non-upwelling ones areas (Stergiou and Christou, this vol.). The low trophic potential of the Mediterranean sets an upper limit in the carrying capacity of the region and, hence, in the level of the catch variability of a given species at a given time (i.e., lower maximum slope values: Fig. 3 and 4).

There remain the questions of whether catch trends reflect abundance trends of similar scales and of what causes trends in fish catches. With respect to the first question, one may assume that fish abundance may exhibit trends similar to those of the catches for the following reasons: (a) although zero catches do not imply zero abundance (e.g., closed fisheries, impossibility to completely fish out a population/species from a given geographic area), annual catches are usually smaller than biomasses; (b) all or most species examined here have been traditionally fished in most FAO subareas and, since catches refer to years following 1970, one may assume that most of the fisheries examined were not in the initial stage of development, at which catch is not related to abundance (Hilborn and Walters, 1992); and finally, (c) many of the catch series used here possibly reflect, at least to a certain extent, management measures that were set based on forecasted abundance level.

With respect to what causes trends in fish catches, climate, predation and its special form of fishing, species' dynamics and life-history, managerial decisions, economic and social factors may all, in a synergetic dynamic fashion, affect fisheries catches (Caddy and Sharp, 1986; Hilborn and Walters, 1992). The effect of climate cannot be distinguished from that of fishing inasmuch as fisheries managers will tend to respond to catch declines by assuming that fishing is the main factor and, hence, both effects will be reflected in catch records (Hilborn and Walters, 1992). However, it is worthy to mention that the fact that the majority of the catch records examined in the present study are characterized by 'reddened' spectra, as is also true of marine physical parameters (Steele, 1985), probably reflects the effect of the such parameters on fish catches.

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