

# Variability of monthly catches of anchovy *Engraulis encrasicolus* in the Aegean Sea

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In a recent paper, Stergiou (1990a) showed that the autoregressive terms of an ARIMA model describing the monthly fishery of the anchovy *Engraulis encrasicolus* in Hellenic waters indicated a 2- to 3-year periodicity in catches. A similar cycle has also been shown for anchovy in the Azov (Dement'eva 1987) and Adriatic Seas (S. Regner 1985). In comparison, long-term periodicities have been shown for *Engraulis mordax* off California (Soutar and Isaacs 1974). In this present study, I examined the variability of the Hellenic monthly catches of anchovy during the period 1964–87 using spectral analysis.

The purse-seine fishery landed 51,282 t of fish which comprised 49% of the total Hellenic catch in 1987 (Stergiou 1990b). Anchovy comprised 46.6% of the 1987 purse-seine catch; the remainder included sardine *Sardina pilchardus*, horse mackerel *Trachurus* sp., bogue *Boops boops*, chub mackerel *Scomber japonicus*, and bonito *Sarda sarda* (Stergiou 1990b). Ninety percent of the mean annual anchovy catch (1964–85) was caught in the northern, northwestern, and western Aegean Sea (Stergiou unpubl. data; no data are available for monthly catches per major fishing area). A recent study of genetic distances, based on electrophoretic

variation, and of morphometric and meristic characters using multivariate analysis does not indicate separate stocks of anchovy (or sardine) in the Aegean Sea (Spanakis et al. 1989).

Monthly catches of anchovy (1964–87, 288 data points) and annual fishing effort (in horsepower, HP) of pelagic seiners were gathered from the Bulletins of the Hellenic National Statistical Service (1968–89). The monthly series was log-transformed and detrended to become stationary. The seasonal component was removed by differencing with lag=12 (Chatfield 1984). To avoid a discontinuity at the end of the data, the resulting series was tapered by 20%. The Fast Fourier Transform was used to compute power spectral estimates, and smoothed (5 moving averages) squared amplitudes of the sinusoids were plotted.

Anchovy catches show a marked seasonal pattern (Fig. 1) and an increasing trend for the years following 1980. The increased trend in catch in recent years has raised concern about whether these high catches are sustainable. Due to higher prices of anchovy since the late 1970s, purse-seine fishing in Hellenic waters is anchovy-oriented rather than sardine-oriented (Stergiou 1986a, 1990a, b). Monthly fishing effort by pelagic seiners is not available. However, annual fishing effort of pelagic seiners increased considerably between 1964 and 1987 (from 363 boats, 20,316 HP, and 6152 tonnage of boats, to 502 boats, 112,310 HP, and 18,922 tonnage of boats; Hellenic Natl. Stat. Serv., 1968–89). Annual catches of anchovy are highly positively correlated with annual horsepower of the pelagic seiners [ $\ln(\text{annual catch}) = 8.25 + 0.000013\text{HP}$ ;  $n = 24$ ,  $r = +0.89$ ,  $p < 0.001$ ] (Fig. 2), indicating that the highly significant linear

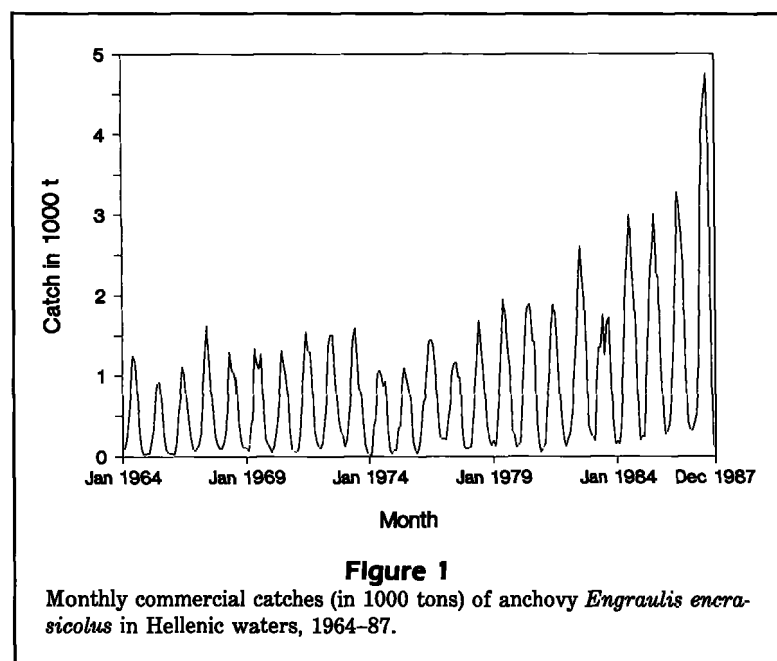
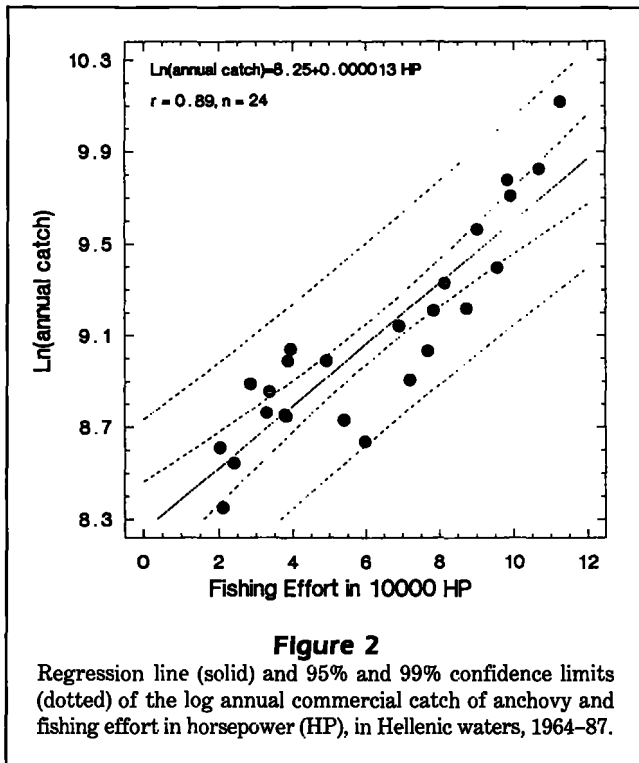


Figure 1

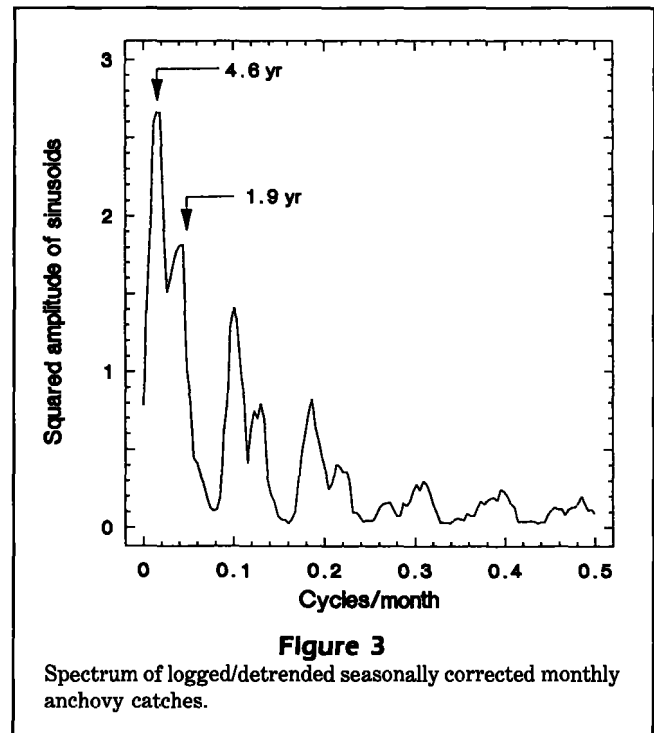
Monthly commercial catches (in 1000 tons) of anchovy *Engraulis encrasicolus* in Hellenic waters, 1964–87.

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**Figure 2**

Regression line (solid) and 95% and 99% confidence limits (dotted) of the log annual commercial catch of anchovy and fishing effort in horsepower (HP), in Hellenic waters, 1964–87.



**Figure 3**

Spectrum of logged/detrended seasonally corrected monthly anchovy catches.

trend in monthly catches [ $\text{Ln}(\text{monthly catch}) = 5.38 + 0.0053T$ ,  $n = 288$ ,  $r = 0.38$ ,  $p < 0.01$ , where  $T = 1-288$ ] is most likely attributed to increased fishing effort.

The spectrum of the resulting series (not shown here), which may be postulated to be free of any annual changes in effort, revealed a large major peak at 12 months (frequency 0.0833). This marked seasonal pattern is most likely related to the seasonal offshore-inshore migrations of anchovy and the nature of the purse-seine fishery (Stergiou 1990a). Purse-seine fishing in Hellenic waters does not occur in the open sea but is mainly restricted to coastal areas where schools of anchovy migrate seasonally. The anchovy starts its inshore migration in early spring, but peak abundance occurs in coastal waters in May–August. Offshore migration probably occurs in late summer–fall.

The smoothed spectrum of the seasonally corrected and detrended series (Fig. 3) reveals a prominent peak at 4.6 years (frequency 0.018) and a probable secondary peak at 1.9 years (frequency 0.043) (95% confidence intervals of the spectrum for 10 df: 0.4882–3.0798 squared amplitude of sinusoids). In contrast, non-sinusoidal periodic variability generates harmonics with periods of less than 1 year (Fig. 3).

Cycles of 2–3 and 4–5 years have also been identified in the air temperature in the northern (Thessaloniki) and western Aegean (Athens) (Table 1) and in different biotic (zooplankton, phytoplankton, fish eggs/larvae,

fish) and abiotic variables (air temperature/pressure, sea temperature/salinity) in different areas of the Mediterranean, Black, and Azov Seas (Table 1). These cycles have also been suggested for annual anchovy catches and eggs/larvae, temperature, salinity, and zooplankton in the Adriatic Sea but the data set is limited (annual, 1962–76) and the cycles may not be statistically significant (D. Regner 1985). Correlations have been found between biotic/abiotic variables (primary production, zooplankton biomass, winds, river flow, air/sea temperature, salinity) and various abundance indices of the Mediterranean anchovy (Azov–Black Sea: Dement'eva 1987, Dekhnik and Rass 1988, Porumb and Marinescu 1979; Hellenic waters: Stergiou 1986b; Adriatic Sea: S. Regner 1985; western Mediterranean: Palomera and Leonart 1989) and other species of *Engraulis* (see Bakun 1985).

Cycles with periods of 2–4 and 4–7 years have also been identified in the physical environment and marine populations in other areas of the world (e.g., Kort 1970, Shuntov et al. 1981, Colebrook and Taylor 1984, Mysak 1986). Such cycles have frequently been related to short-term ocean-atmosphere interactions (e.g., surface heat-exchange phenomena: Zupanovich 1968, Colebrook and Taylor 1984; advection: Kort 1970, Mysak 1986).

A comprehensive discussion of the mechanisms underlying such variability requires adequate biological

**Table 1**

Cycles identified in the variability of various climatic and biological parameters in the Mediterranean–Black Sea ecosystem. T = type of data (A = annual, M = monthly, D = daily); P = time period of available data; Me = method of analysis of data (sa = spectral analysis, acf = autocorrelation function, cgm = composite graphic method, i.e., comparison of graphs; see Dement'eva 1987).

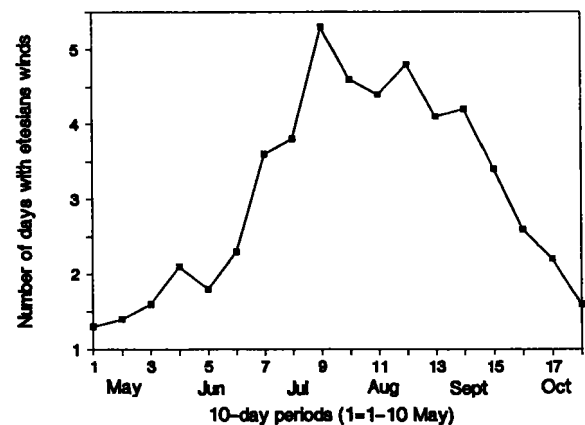
Variable	Area	T	P	Me	Cycles, in years		Source	
Sardine catch*	Adriatic	A	1853–1960	sa	2.3	3–3.5	Zupanovic 1968 Regner and Gacic 1974	
Sardine catch	Hellas	M	1964–1982	sa		3.3	Stergiou 1988	
Anchovy catch	Hellas	M	1964–1987	sa	1.9	3.3	4.6	This study
Anchovy catch*	Azov Sea	A	1955–1981	cgm	2–3		Dement'eva 1987	
Carp catch*	Hellas <sup>a</sup>	A	1947–1983	sa		3–4	Economidis et al. 1988	
Perch catch*	Hellas <sup>a</sup>	A	1947–1983	sa		3–4	Economidis et al. 1988	
Copepods	Adriatic	M	1970–1974	acf	2–3		D. Regner 1985	
Fish larvae	Adriatic	M	1971–1977	acf	3		S. Regner 1982	
Fish eggs	Adriatic	M	1970–1974	acf	2–3		D. Regner 1985	
Primary production	Adriatic	M	1970–1974	acf	2–3		D. Regner 1985	
Diatoms*	Black Sea	A	1954–1987	sa	2.9	4.5	Petrova-Karadjova and Apostolov 1988	
Air temp.*	Hellas <sup>b</sup>	A	1892–1981	sa	2.2–2.3		Flocas and Giles 1984	
Air temp.*	Hellas <sup>c</sup>	A	1859–1981	sa	2.2–2.3		Flocas and Giles 1984	
Air temp.*	Trieste	A	*	sa	2–2.9		Polli 1955	
Air pressure*	Trieste	A	*	sa	2.3		Polli 1955	
Air pressure*	Venice	A	*	sa	2.1–2.8		Polli 1955	
Sea surface temp.	Adriatic	M	1970–1974	acf	2–3		D. Regner 1985	
Sea surface temp.	Monaco	D	1946–1961	sa	1.8	4.4	Bethoux and Ibanez 1979	
Sea surface salinity	Adriatic	M	1970–1974	acf	2–3		D. Regner 1985	

\* Together with cycles of 8–12 years (frequently related to the 11-year cycle in sunspot number, e.g., Gnevyshev and Ol' 1977).

<sup>a</sup> Lake Koronia, <sup>b</sup>Thessaloniki in summer, <sup>c</sup>Athens in summer.

and physical oceanographic information, probably on time scales of a few days and spatial scales of <1 km (*sensu* Leggett 1986). This information is not currently available. The distribution and biology of larval, juvenile, and adult anchovy and larval dispersal patterns have not been studied in Hellenic waters. However, some preliminary, conjectural discussion is presented here.

The anchovy spawning season in the eastern Mediterranean extends from April to September with a peak in the summer months (Demir 1965, S. Regner 1985). Anchovy larvae and postlarvae occur in the plankton between May and September with a peak in July–September (S. Regner 1985). This corresponds to the predictable period of the etesians winds. These dry northern, northeastern, and eastern winds blow each year over the Aegean Sea from the end of May until the end of October with a maximum frequency in July–August (Fig. 4; Carapiperis 1962, Mariopoulos 1961). Since anchovy spawning in the eastern Mediterranean does not seem to be affected by abiotic factors such as temperature or salinity (Demir 1965, S. Regner 1985), the summer spawning habit of anchovy may represent an important adaptation to the highly oligotrophic conditions of the stratified coastal Aegean waters in summer. By spawning in summer, anchovy larvae (1) do

**Figure 4**

Mean number of days with etesians winds in Athens for May–October, 1893–1960 (data from Carapiperis 1962).

not compete with sardine larvae which occur in the plankton mainly in winter and spring (Yannopoulos 1977, Daoulas and Economou 1986, Regner et al. 1987), and (2) are released in a relatively food-rich environment due to the effect of the etesians winds. The increased frequency and intensity of the etesians winds

over the Aegean Sea in July–August when they frequently reach gale force (Carapiperis 1962) would probably deepen the mixed layer, and hence entrain nutrient-rich water from below the thermocline. Mullin et al. (1985) have shown that microzooplankton biomass and chlorophyll *a* levels can be doubled after wind-related events. In addition, an increase in the frequency and intensity of etesians winds may also result in an intensification of upwelling in the northern, northeastern, and eastern part of the Aegean Sea (Metaxas 1973, Theocharis et al. 1988). Hence, periods dominated by higher-than-average frequency of etesians in July–August may be associated with favorable feeding conditions for anchovy larvae which may be subject to lesser mortalities through starvation and predation, the main factors affecting larval mortality in Mediterranean anchovy (Azov–Black Sea: see Dekhnik and Rass 1988 for a review; Adriatic Sea: see S. Regner 1985 for a review; western Mediterranean: Palomera and Leonart 1989).

Other factors may also affect variability in the anchovy abundance. For example, climatically-mediated long-term changes in production and plankton species composition in the eastern Mediterranean, changes in larval dispersion due to changing patterns of currents, as well as other factors, intrinsic or extrinsic, may affect the egg/larval/postlarval/juvenile phases. It has been maintained that in periods of increased air pressure gradient over the eastern Mediterranean, the water exchange between its basins intensifies (Pucher-Petkovic et al. 1971, Vucetic 1981). As a result, the salinity, nutrient content, temperature, and primary productivity of the Adriatic Sea and of the eastern Mediterranean basin rise, and the species composition of the phytoplankton community changes. These changes were accompanied by changes in the total biomass of small pelagic fish (sardine, anchovy, horse mackerel, etc). Such climate-plankton-small pelagic fish interactions in the eastern Mediterranean involve time lags of 2–3 years (Pucher-Petkovic et al. 1971). Lastly, cycles in anchovy catches may also be the result of social-economic factors (Stergiou 1991) and/or a change in the anchovy availability to purse seiners (changes in the distribution and/or density of schools as a response to changes in atmospheric and/or marine climatic patterns) rather than to changes in the abundance of anchovy itself.

Incorporation into management schemes of these cycles in abundance (e.g., Taylor and Prochaska 1984) is particularly important for anchovy and other small pelagic fish which are prone to collapse under intense fishing pressure and poor recruitment.

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