NONLINEAR RESPONSE OF BLACK SEA PELAGIC FISH STOCKS TO OVER-EXPLOITATION

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Abstract
A three trophic levels prey-predator model investigates the nonlinear dynamics of the long-term (1960 - 1999) changes in pelagic fish stocks of the Black Sea. The equilibrium analyses first explore the quasi-steady state dynamics of the system under various combinations of the consumption, harvesting and mortality rate values. This knowledge is then used to study the time-dependent nonlinear dynamics and to describe the progression of stocks under temporally varying harvesting conditions. Despite the idealized structure of the model, the simulations reproduce the observations reasonably well. The solutions indicate multiple equilibria of the system and successive "discontinuous" and "smooth" regime shifts between the alternate states controlled by a delicate balance of the consumption and harvesting rates.
Keywords : Black Sea, Models, Fisheries.

Recent studies [1,2] noted the inevitable role of the trophic cascade process under marked changes in the higher trophic level structure of the Black Sea in response to the excessive and continual harvesting of stocks at different periods of the recent past. The quantitative understanding of the likely response of pelagic fish stocks to over-exploitation thus constitutes one of the key issues to gain a deeper insight into the mechanisms that govern the long-term organization of the ecosystem. For this purpose, a simple deterministic model is developed to explore the nonlinear dynamics associated with the long-term stock variations under differing harvesting conditions.
The model is composed of the small pelagic (resource), medium pelagic (consumer) and large pelagic (top predator) groups; the latter involving both large pelagics (with size >90 cm) and dolphins. The small pelagic group grows using resources provided by the lower trophic level, and is consumed by both medium pelagic and top predator groups. As the top predator and the consumer groups compete for a single resource, the predator group feeds on the consumer group as well. For simplicity, demersal stock variations and their interactions with small pelagics are not explicitly taken into account because of their negligible role in the Black Sea fishery after the 1960s. All groups are subject to linear harvesting, and the system is closed by the quadratic mortality terms for the top predator and medium pelagic groups. Further details on the model are given in [3]. The simulated stock and catch variations agree well with the observations despite the simplicity of the model dynamics (Fig. 1).

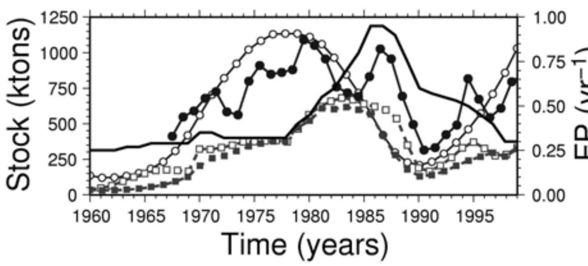

Fig. 1. Temporal variations of the observed (bold circles) and simulated (open circles) stock biomass (ktons), and the observed (bold squares) and simulated (open squares) catch (ktons) for small pelagics. The straight line represents the fishing mortality of small pelagics (yr^{-1}) used in the simulations.

The small pelagic stock possesses three distinct successive transitions between its low regime (<350 ktons) and high regime (>950 ktons). The first transition (TR1) comprises the period from 1969 to 1973, during which it switches to the high stock regime. The shift occurs at the large pelagic fishing mortality threshold rate of $f_3 \sim 0.55$, at which the top predator stock drops below the threshold value of 40 ktons. Upon increasing f_3 to 0.7, the top predator stock decreases further and vanished by the mid-1970s, which coincides with the transitional period from the low to high stock regime of small pelagics. The transition of the medium pelagic stock from the low stock regime (less than 60 ktons) to the high stock regime (greater than 180 ktons) follows that of small pelagics with some time lag.

The high stok regime of small pelagics persists until 1982, after which the second transition (TR2) during 1983 - 1986 brings the stock back to its low stock regime. TR2 begins at the small pelagic stock harvesting rate $f_1 \sim 0.6$. Above this threshold f_1 value, small pelagic stock is continually depleted at the expense of maintaining a steady catch level around 600 ktons. As the stock approaches the low stock regime for $f_1 > 0.6$, the catch then drops dramatically down to $\sim$ 150 ktons within a few years. The medium pelagic stock increases up to 250 ktons until 1984 under low fishing mortality rates around 0.3 - 0.4. Thereafter, as the fishing mortality rate gradually rises to $\sim$ 0.6, the stock starts declining within the high stock regime and finally switches back into the low stock regime during 1988 - 1989 concurrently with small pelagics. At the medium pelagic stock harvesting rate $f_2 \sim 0.6$, the catch becomes as high as 120 ktons and then drops abruptly to less than 60 ktons as the stock tends to approach the low stock regime. Thereafter, the medium pelagic stock remains within the low stock regime until the end of the simulation period for decreasing fishing mortality rate to 0.4.
The low stock regime of small pelagics lasts only four years. Once its fishing mortality rate falls below the threshold value of 0.6 by 1993, the stock starts increasing linearly (i.e., the third transition, TR3) and moves into the high stock regime at 1998 when $f_1 \sim 0.3$. Although the range of f_1 between 0.45 and 0.60 during the transition governs the ultimate stock size of small pelagics in the high stock regime, the crucial factor which promotes the switch is the specific choice of f_2 values. Values greater than 0.4 support the increase in the small pelagic stock but keep the medium pelagic stock depleted. Smaller values force the transition of small pelagic stock to take place at the lower f_1 threshold values and to accompany a certain increase in medium pelagic stock. The latter case presents a stock recovery option with the existence of balanced stocks of both small and medium pelagics in the system.

References

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