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Intraseasonal characterization of glass eel migration in the River Tiber: space and time dynamics

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Glass eel (*Anguilla anguilla*) upstream migration was studied in the River Tiber estuary to obtain a better understanding of spatial and temporal migration dynamics within the season of ascent. Using data from glass eel fisheries, time series analysis of daily catches per unit of effort revealed a fortnightly cycle that can be related to invasion waves possibly corresponding to tidal currents. The amplitude of these waves appeared to correspond to the tidal area of the estuary. Furthermore, glass eels apparently had a delay in this area before resuming upstream migration.

Key words: glass eel; *Anguilla anguilla*; upstream migration; River Tiber.

INTRODUCTION

European glass eel (*Anguilla anguilla* L.) migration has been monitored widely because they are harvested commercially in many estuaries of Europe, on both the Atlantic and the Mediterranean coasts. A survey of the literature points to a dramatic decline in catches for several European countries in the last decade (Moriarty, 1990, 1993). However, capture data for Italy are scarce, despite the long standing glass eel fisheries both in the Tyrrhenian and North-Adriatic regions.

In the lower stretch of the River Tiber, a large eel population is present which is prevented from moving further upstream by a series of dams, the first of which is located about 40 km from the sea. This is the main cause of a high yellow eel density exploited by a fishery also as a consequence of the increased seed demand from intensive eel culture.

The aim of this study was to gain further information about glass eel recruitment to the River Tiber, and to understand the dynamics of glass eel migration through the estuary.

MATERIALS AND METHODS

The study area was located at the mouth of the River Tiber (Latium, Central Italy), whose coastal plain estuary (Pritchard, 1952) consists of an enlargement of the river axis into which sea water intrudes, creating a salinity stratification. This salinity front extends about 7 km from the river mouth, although its amplitude depends on tide and river discharge. The study area stretched from the sea to approximately 10 km upstream. Along this stretch, 20 fixed stations 600 m apart were chosen where elver fyke nets were

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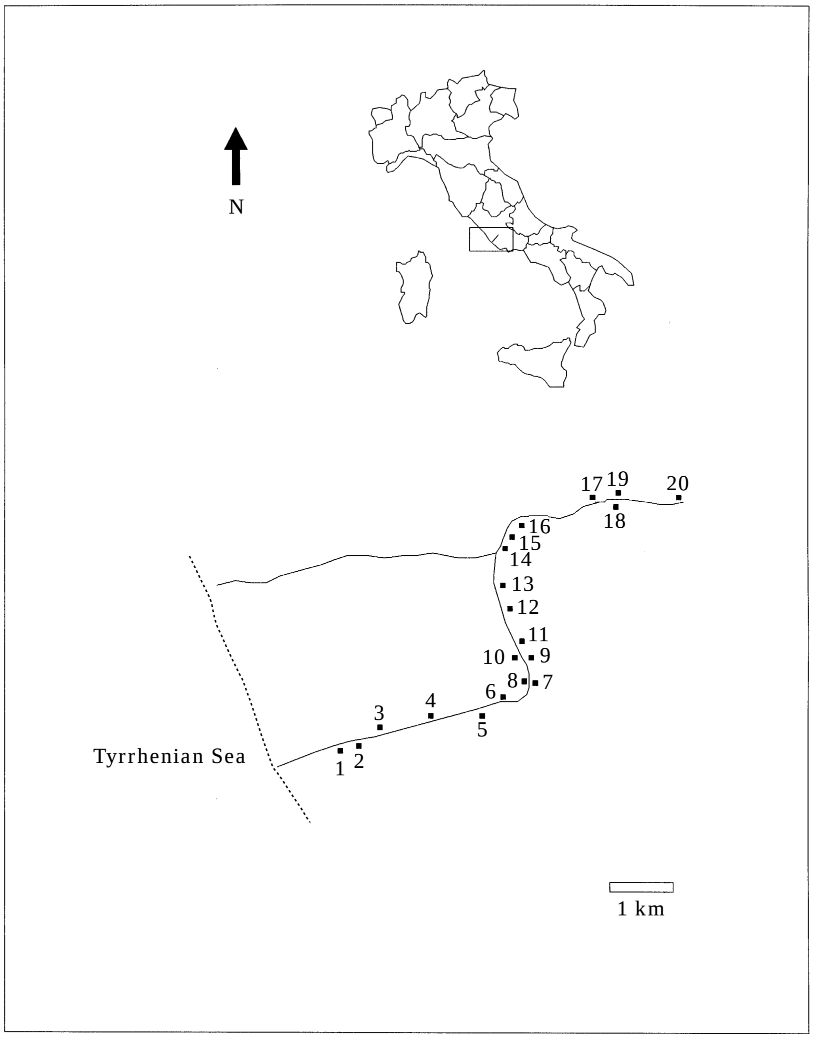

FIG. 1. Fishing stations where fyke nets were installed for the monitoring of glass eel upstream migration in the Tiber estuary.

used (Fig. 1). Frequency of fishing was daily, except during unusual events such as river floods and storms.

Global data from two fishing seasons were available (Table I), from December 1990 to March 1991 and from November 1991 to March 1992, but daily data were available only from January 1991. The fyke nets (total length 4·6 m, two capture chambers, mouth 1·2 m wide, mesh 2 mm) were provided with two large wings (2·5 m long, mesh 2 mm) to direct swimming glass eels towards the mouth. Fyke nets were installed (one per station) usually at noon, tied to wooden supports with the mouth oriented downstream, and withdrawn the following morning. Catches for each fyke net and total catch of the day were weighed. The number of nets installed and the frequency of emptying varied with the intensity of glass eel ascent. Analyses were therefore carried out using daily catches per unit of effort (cpue) as the most representative relative abundance index. Cpue was calculated as daily total catch per number of fyke nets installed each day.

An autocorrelation was performed on the cpue time series using Moran's index I to detect a temporal periodicity in catches within the season of migration. This auto-

TABLE I. Comparative aspects of fisheries in the two seasons

	First season 1990–1991	Second season 1991–1992
Duration (days)	117	153
Fishing	94*	73
No fishing	23	80
Total catch (kg)	446	256
Mean daily catch (kg)	4·7	3·5
Mean sets of gear installed per day	7	6
Mean duration of fishing effort per day (h)	15	15

*Daily catches for the first season were available only from January (i.e. 42 days).

correlation index (Moran, 1950), developed for the analysis of spatial series, was selected because the cpue time series was scattered. Two-tail tests were performed, with a chosen probability level of $P<0{\cdot}05$, on the whole cpue series of the two seasons and separately for the two seasons.

To study the spatial pattern of migration in the estuary, cross-correlations were performed on the catch time series from the second season. Stations 19, 15, 11, 7, 6 and 3 (see Fig. 1) were chosen, because these were the stations most frequently used during the two fishing seasons. The correlations were calculated for paired stations on catch time series shifted for time lags from 0 to 90 days.

RESULTS

The second fishing season was longer than the first (Table I), but the days of actual fishing were fewer, because for the most part of November 1991 a flood hampered the installation of nets.

TIME DYNAMICS

Maximum abundances were recorded during February of both seasons (Fig. 2). In March the yield decreased progressively towards minimum values. Therefore, the fishing season ended in both years at the end of March. Autocorrelation showed the existence of periodicity within the whole cpue time series (Fig. 3). The periods which explained the greater part of the variance of the series were those for which the correlation coefficients, r, were significantly different from zero, i.e. higher than the confidence limits $p(r)$. A strong positive autocorrelation was found for very short time lags (1 to 2 days), which accounted for the dependence of catches within short term cycles. In the analysis of periodic data series, this is usually due to the existence of a longer cycle. In fact the most striking result was a fortnightly cycle: within the first season, autocorrelation was positive and significant at 13 to 14 days. Even at a time lag of about 1 year, i.e. comparing the first and the second fishing season, there was strong evidence of a 14-day period. There was also weak evidence for a second peak of positive autocorrelation at about 28 days, but this was probably a side effect of the fortnightly cycle.

Significant negative autocorrelations were observed, within the second fishing season, at 7 and 21 days (Fig. 4) due to the same basic frequency of the data series.

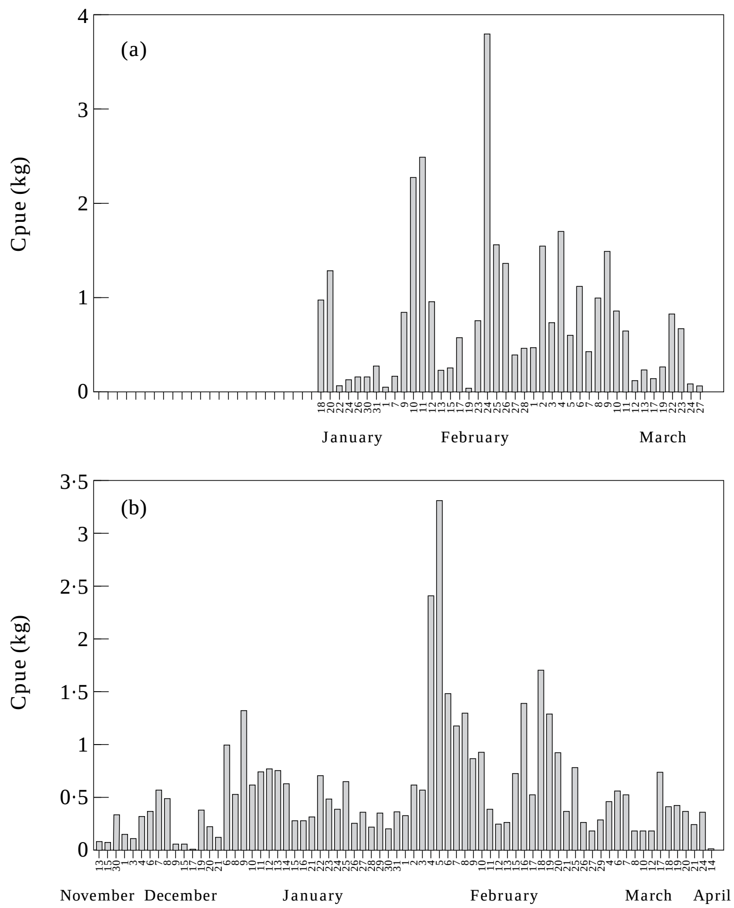

FIG. 2. Catches per unit of effort (daily total catch/number of fyke nets installed each day) during glass eel upstream migration in the Tiber estuary. (a) First fishing season (January–March 1991). (b) Second fishing season (November 1991–April 1992).

SPACE DYNAMICS

The significant positive correlation coefficients at definite time lags between pairs of stations point to a direct proportionality in catches between those stations (Table II). Significant positive instantaneous cross correlations recurred at intervals of 0 to 3 days, between all pairs of stations except those farthest away. Peaks of high positive cross correlations with a period of 14 days can be observed for many pairs of stations. This cyclic cross correlation was always significant ($P<0{\cdot}01$) for all stations compared with station 3 (downstream) (except for station 19 for which data were scarce) and for many pairs of neighbouring stations. Cross correlation between stations at longer time intervals occurred in many cases, with intervals ranging from 28 to 56 days.

DISCUSSION

Annual recruitment in the River Tiber was determined mainly by the timing of ascent, which took place between November and February. As fishing effort

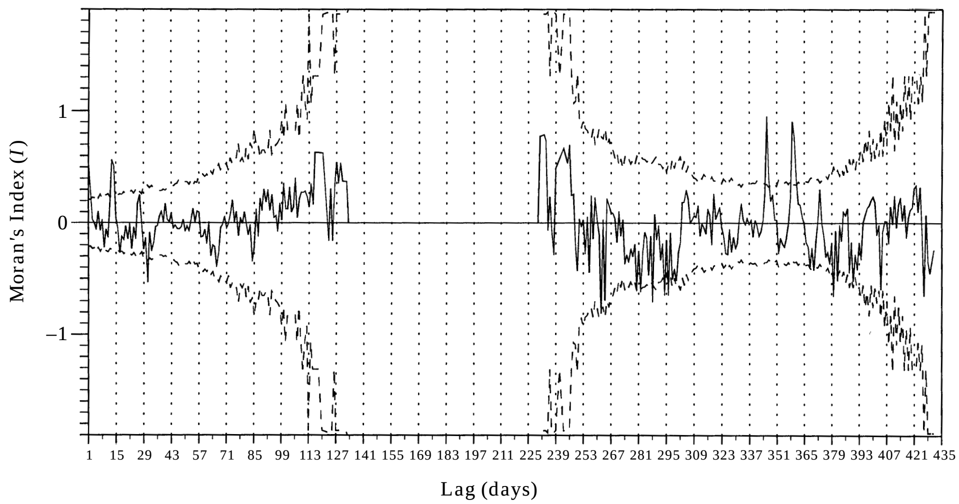

FIG. 3. Autocorrelation (Moran's) diagram of the two fishing seasons cpue time series of glass eels during upstream migration in the Tiber estuary (dashed lines are 95% confidence levels).

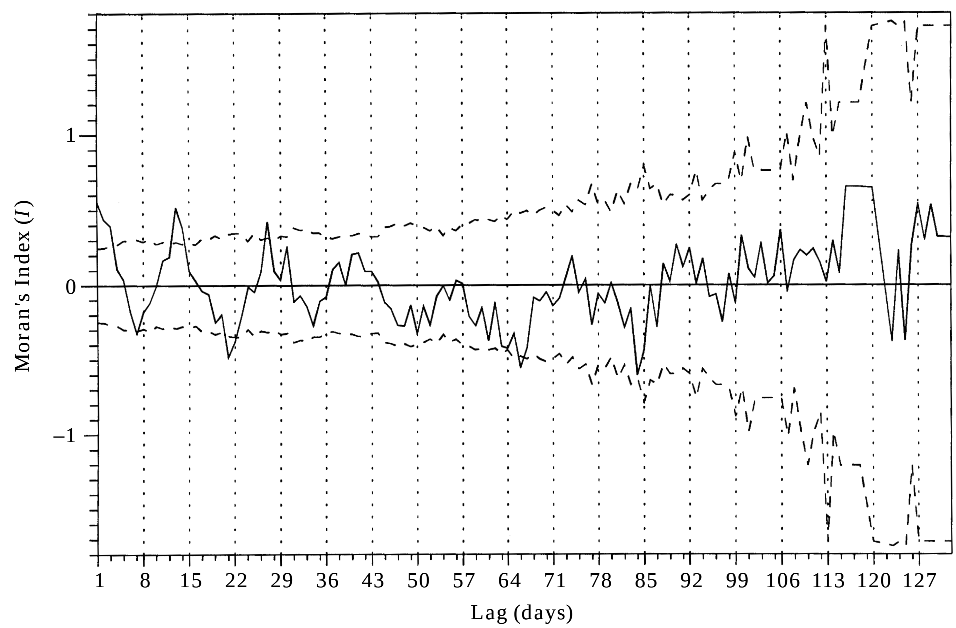

FIG. 4. Autocorrelation (Moran's) diagram of the second fishing season cpue time series of glass eels during upstream migration in the Tiber estuary (dashed lines are 95% confidence levels).

remained reasonably constant in the two sampled seasons, daily catches were comparable. The fortnightly cycle in the cpue time series points to a periodicity of glass eel ascent, and supports the hypothesis that glass eel migration consists of waves of invasion (Boëtius & Boëtius, 1989). This oscillatory pattern, observed by many authors (Jellyman, 1979; Cantrelle, 1984; Gandolfi *et al.*, 1984; Sorensen & Bianchini, 1986; Boëtius & Boëtius, 1989), is probably related

TABLE II. Time lags $d(t)$ in days at which r, correlation coefficient between catches in paired stations, is significant ($* = P < 0.05$; $** = P < 0.01$)

Station	Station					
	19	15	11	7	6	3
19	—	0** 36* 45** 53*	0* 40* 42** 43**	0* 35* 37** 38**	27* 37**	—
15		—	0** 2** 5* 14*	0** 40** 42**	0** 1** 15* 30** 42* 56**	0* 3* 12* 13** 14* 26** 39* 40** 41*
11			—	0** 1* 2** 14* 22* 35** 38**	1* 51** 52* 53*	0** 11** 26** 27** 48**
7				—	0** 1* 29*	0** 11* 12* 13** 26**
6					—	0** 1* 11** 22* 39** 40**

to the selective tidal stream transport described both for *Anguilla rostrata* (Lesueur) (McCleave & Kleckner, 1982; Wippelhauser & McCleave, 1987; McCleave & Wippelhauser, 1987) and *A. anguilla* glass eels (Creutzberg, 1963; Gascuel, 1986). According to this model, the rate of upstream transport depends upon the interactions between the behaviour of the fish and the hydrographic conditions in the estuary. The estuarine hydrodynamics should in fact bring about a natural trapping of animals in the tidal front, the location of which depends on the freshwater discharge and the tide strength.

The peaks of abundance in catches with a 2-week period can probably be ascribed to successive runs of glass eels in coincidence with tidal currents in the Tiber estuary. This seems to be confirmed by the proportionality in catches between all stations with a time interval of 0 to 3 days: in fact the greater the tidal amplitude, the farther upstream the glass eels should be transported (Gascuel, 1986). The amplitude of these waves of invasion declined towards the upstream part of the study area, probably due to a transition stage in this stretch of the river. After invasion of fresh water from the sea, glass eels remain in estuarine and tidal areas while they undergo an adaptation period in behaviour and morphology before their upstream migration (Deelder, 1958, 1960; Tesch, 1971; Weber, 1986). McCleave & Wippelhauser (1987) suggested that it is the tidal regime that determines the location of this ' transition area ', rather than salinity or temperature choices. Internal morphology of glass eels caught during migration also indicates that they remain in brackish waters (Ciccotti *et al.*, 1993). The correlation between catches in paired stations at time intervals other than 0 to 3 days further supports a slowing and/or halt in migration, since it points to a delayed resumption of migratory movement. The cyclic correlations between catches at time lags of 14 days suggest, however, that further movements towards the upstream stretch of the study area were still linked to tidal currents. According to Gascuel (1986), upstream of the tidal area the moving forward of glass eels involves an active swimming behaviour. It is during this second phase that glass eels, having now developed into elvers, are able to move further upstream and colonize the upper part of the river system.

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