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Creating a Geographical Information System for Freshwater Crabs and Fishes in Greece

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ABSTRACT

A geographical information system (GIS) for freshwater crabs and fishes in Greece was created in response to the European Environmental Agency's (EEA) biodiversity initiative for European Union countries. A total of 1931 collections, made with seines, dipnets, and backpack electroshockers in 32 drainages of Greece, yielded 126 species of fishes and crabs in 2,359 data records including species, latitude, longitude, drainage, prefecture, and locality; 731 also include stream order, elevation, gradient, stream width and depth, pH, temperature, and distance to river mouth. Our GIS indicates current distributions of species, species rich and poor areas, anomalous species distributions, areas warranting further sampling, and cogeneric species whose overlapping ecological distributions call for taxonomic and phylogenetic investigation. In applied studies, the freshwater GIS can be an integral tool for EEA's biodiversity inventory of the southern Balkan peninsula, an inland fisheries management plan, designs for environmental impact studies, and conducting gap analyses for the region.

Keywords: Greece, aquatic biodiversity, geographical information system, GIS

INTRODUCTION

Geographic information systems (GIS) are being used to protect terrestrial and aquatic biodiversity through the use of gap analysis, a GIS methodology that identifies distribution of biodiversity over large spatial areas (Meixler and Bain, 1999). Gap analysis has been used to overlay lands in parks and protected wilderness areas (e.g. national parks and preserves) with the ranges and habitats of the flora and faunas in the region to identify unprotected areas rich in biodiversity, particularly endangered species. Subsequently, these overlays are applied to direct management and conservation efforts in given areas (Meixler and Bain, 1999; Scott et al., 1993). Recently, gap analysis has been used by aquatic researchers to predict aquatic biodiversity at the community and species levels for varying spatial scales in North America (Meixler and Bain, 1999).

Smith and Gillett (2000) used gap analysis to study the distribution and conservation status of European temperate forests in support of the World Wildlife Fund's forest strategy for Europe. However, gap analysis has not become part of the European Environmental Agency's (EEA) protocol for freshwater ecosystems.

The EEA published a biodiversity initiative to inventory, identify and describe aquatic and terrestrial species in European Union (EU) countries (Nixon et al., 1996).

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To date, few studies exist to document the aquatic life in Greece, yet the country is home to one of the richest freshwater ichthyofauna in Europe (126 fish taxa: 97 species and 29 subspecies of primary or secondary freshwater fish species) (Maurakis and Economidis, 2004). Over 33 % of the native fish fauna in Greece is imperiled and/or extirpated (two extinct fish species, five listed as critically endangered, and 29 considered endangered and/or vulnerable)(Bobori et al., 2001). Continued decimation of fish populations occurs through pollution, introduction of exotic species, habitat alteration (i.e., damming, stream channelization, canalization, riparian destruction), stream desiccation (a result of water abstraction for crop irrigation and potable water supplies), and natural perturbations (e.g. drought) (Bobori, et al., 2001; Maurakis and Grimes, 2003). Four species of freshwater crabs (*Potamon fluviatile*, *Potamon ibericum*, *Potamon rhodium*, and *Potamon potamios*) are extant in Greece, but distributional information for the species is limited, as many areas in the country have not been sampled (Maurakis et al., 2004).

In response to the EEA's biodiversity initiative, our primary objective is to present the first geographical information system for freshwater crabs and fishes in Greece. Ancillary objectives are to outline the use of a GIS in Greece and the southern Balkan peninsula, and to identify other sources of data that can be incorporated into the GIS for freshwater crabs and fishes in Greece.

STUDY AREA

Lotic freshwater systems in Greece (132,000 km^2; cf. Virginia= 110,800 km^2) are relatively harsh environments with limited water budgets as a result of the country's complicated geological history, and Mediterranean climate with low annual rainfall (Hadjibiros et al., 1998; Gretes and Maurakis, 2001). Quaternary geomorphological alterations and regional macroclimatic variations have contributed to relatively short (maximum length=~320 km for the Aliakmon River in Greece), alkaline river drainages in Greece (Hadjibiros et al., 1998; Maurakis et al. 2001, Skoulikidis et al., 1998). Over 85 % of freshwater resources are derived from surface waters; greater than 80 % of total surface discharge (35 billion m^3) originates from eight drainages (Kalamas, Arachthos, Acheloos, Aliakmon, Axios, Strymon, Nestos, and Evros)(OECD, 2000)(Fig. 1). Subterranean aquifers supply ~ 40 % of irrigation waters (Skoulikidis et al., 1998). During the past two decades, surface runoff has decreased significantly and has resulted in numerous permanent rivers becoming xeric during the dry season often leaving a series of pools not interconnected through surface flows, and water supplies barely meeting potable and irrigation requirements in parts of the country (Skoulikidis et al., 1998).

MATERIALS AND METHODS

A total of 2,359 data records for 122 fish species and four crab species by latitude, longitude, drainage, prefecture, and locality were obtained from 32 freshwater systems from collections made by Aristotle University (1,568 records) and Science Museum of Virginia (791 records) and stored as a dBase file (.dbf format). Latitude and longitude were derived from a Garmin e-Map GPS or by identifying collection localities on Garmin's MapSource™ WorldMap, version 3.0. Of this total, 731 data records also included information for stream order (1, 2, 3, 4, 5), elevation (m), stream gradient (m/km), stream width (m), stream depth (m), pH, water temperature (^oC), and

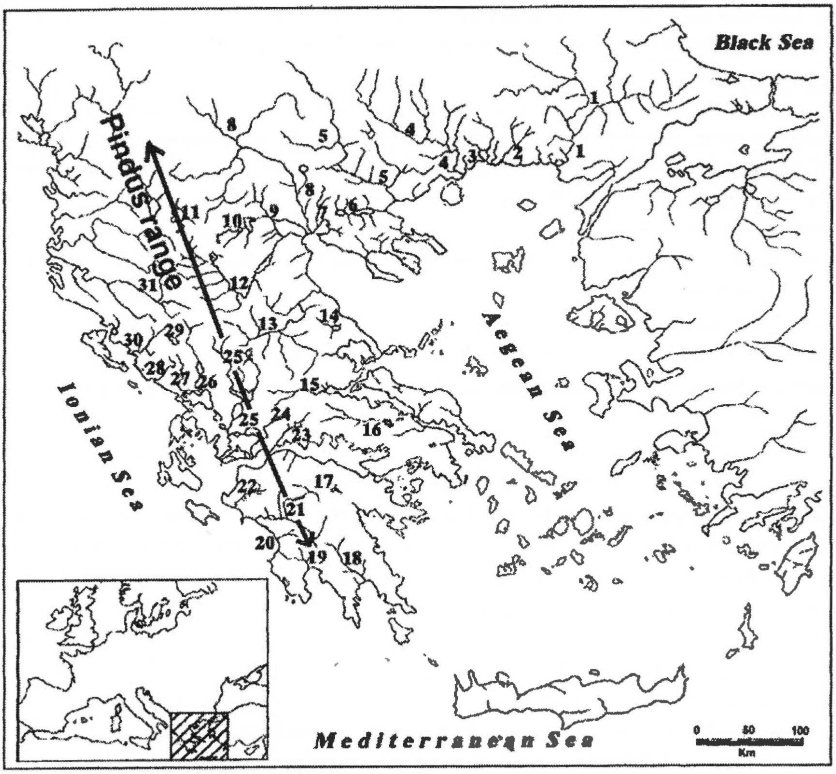

FIGURE 1. Major freshwater drainages, lakes and aquatic systems in Greece. 1. Evros River, 2. Filiouris River, 3. Lake Vistonis, 4. Nestos River, 5. Strymon-Aggitis River, 6. Lake Koronia and Lake Volvi system; 7. Gallikos River. 8. Axios River and Lake Doirani, 9. Loudias River, 10. Lake Vegoritis, 11. Lake Prespa system, 12. Aliakmon River and Lake Orestias (Kastoria), 13. Pinios River (Thessaly), 14. Lake Karla and Velestino Springs, 15. Sperchios River, 16. Lakes Yliki and Paralimni and Kifissos River system, 17. Lake Stymphalia, 18. Evrotas River, 19. Pamisos River, 20. Nedas River, 21. Alphios River, 22. Pinios River (Peloponnesos), 23. Mornos River, 24. Evinos River, 25. Acheloos River and Lakes Trichonis-Ozeros-Amvrakia and reservoirs Stratos-Kastraki-Kremasta-Tavropos, 26. Arachthos River, 27. Louros River, 28. Aheron River, 29. Lake Pamvotis (Ioannina), 30. Kalamas River, and 31. Aoos River.

river kilometer (km), the distance between each collecting location and its corresponding river mouth. ESRI's "Digital Chart of the World" 1:1,000,000 (ESRI 1999) was used to generate base map data themes (e.g. political boundaries and oceans, elevation zones, drainage, populated places, land cover types, and utilities) of towns, roads, shorelines, water features, railroads, elevations and landform data. Arcview GIS 3.2 was used to create themes (e.g. single or multiple species) and to plot species distributions relative to ERSI's base layer data. Governmental organizations (GOs; Greek Ministry of Environment, Physical Planning and Public Works, Hellenic Center for Marine Research-Institute of Inland Waters, and University of Athens, University of Crete, University of Ioannina, National Technical University) and non-governmental organizations (NGOs: Greek Biotope/Wetland Center) were surveyed to identify the informational content of their holdings of freshwater crabs and fishes that could be included in the GIS (Table 1).

TABLE 1. Number and percent (%) of collections of freshwater crabs and fishes of Greece housed in Greek governmental and non-governmental institutions, and Science Museum of Virginia.

Organization	Collections #	Collections %
Aristotle University and Science Museum of Virginia	1931	82.5
Greek Biotope/Wetlands Center	135	5.8
National Technical University	127	5.4
Hellenic Center for Marine Research-Institute of Inland Waters	101	4.3
University of Athens	47	2.0
University of Ioannina	0	0
University of Crete	0	0
Ministry of Public Works, Planning, and Environment	0	0
Total	2341	100

RESULTS AND DISCUSSION

Our GIS for freshwater crabs and fishes in Greece is the first attempt to organize and present distributions of aquatic species in freshwaters of the country. Attributes of a GIS (i.e., the ability to interactively query and spatially analyze biotic data relative to other data types such as physiographic, demographic, and land cover) can be used effectively to promote data sharing, enhance communication among widely disparate disciplines, and facilitate decision-making in an EU country where communication among governmental and non-governmental agencies historically has been poor (Bobori et al., 2001). For example, Greece has no national action plan for inland waters, habitats, and fisheries coupled with an action plan for terrestrial ecosystems, and domestic and tourism development (Bobori et al., 2001). Further, unsustainable agricultural policies, and water and soil resource schemes have resulted in loss of 75 % of wetlands in Greece since 1900 (OECD, 2000). A GIS that contains distributions of aquatic species in Greece's freshwater environs is the first requisite step in creating a national action plan in a country where natural perturbations (e.g. droughts) and increased anthropogenic influences (i.e., water abstraction, canalization, stream channelization, damming, introduction of exotic species, and agricultural, industrial, and municipal waste inputs) on freshwater resources have become more intense over the past 40 years (Bobori, 1996; Hadjibiros et al., 1998; Lekakis, 1998; Economidis et al., 2000; Economou et al., 1999; OECD, 2000).

From our survey of organizations with data on freshwater crabs and fishes in Greece, we identified 410 collections (17.5 % of our total number of collections) made by seven Greek GOs and NGOs that can be integrated with our GIS (Table 1). We are working with Greek colleagues to overcome the primary problem with some of these data: the absence of exact descriptions of where collections were made, which precludes assigning latitude and longitude coordinates and inclusion of the data in our GIS.

A GIS of freshwater species in Greece has the potential to contribute significant information and analyses in several areas. For example, from a biological function, a freshwater biotic GIS can expose un-surveyed areas warranting biological reconnaissance surveys; clarify anomalous species distributions; identify species poor and species rich areas; and specify cogeneric species whose overlapping ecological distributions call for taxonomic and phylogenetic investigation. For example, Maurakis et al. (2004) identified eight relatively large areas that have not been surveyed among the current distributional ranges of the four species of *Potamon* in Greece (Fig. 2). Identifying which species of *Potamon* exist in these areas is relevant to testing biogeographical hypotheses and evaluating environmental policies. We also identified anomalous distributions of some *Barbus* species (e.g. *Barbus plebejus*, *Barbus meridionalis*, and *Barbus* sp.) in Greece, which points to a re-examination of specimens of suspect identifications in museum holdings (Fig. 3). For example, *Barbus plebejus* is restricted to the Adriatic drainage of Italy and Croatia; *Barbus meridionalis* occurs only in southern France and northeastern Spain (Kottelat, 1997); and the *Barbus* sp. should be identified if specimen condition and size permit. Relative to species-poor areas, the GIS can distinguish areas that have low species diversity from those (e.g. higher elevations of Pindus mountain range) that have been sampled inadequately (Figs. 1 and 4).

Our GIS is being applied to other studies. For example, Maurakis and Economidis (2003) are using the freshwater biotic GIS as the source to create distributional maps of fishes as they update their classification key when new species are described and relationships and taxonomic status of others (e.g. *Cobitis* species) are clarified (Fig. 5). Results of phylogentic investigations and known distributions of species of *Cobitis* indicate two waves of dispersal of cobitid ichthyofaunas from Danubian drainages (Fig. 6), which is not supported by cladistic analyses of relationships of river drainages in the southern Balkan peninsula based on distributions of cyprinid species (Maurakis et al., 2001). Reexamination and clarification of distributions of all species via GIS also will provide an independent means to check distributions prior to further hypothesis testing of conflicting conclusions of biogeographic ichthyofaunal divisions of the Balkan Peninsula of Maurakis et al. (2001) and Maurakis and Economidis (2001)(Figs. 7 and 8) based on cladistic methods versus those by Economidis and Banarescu (1991) and Bianco (1990) based on traditional evolutionary methodologies.

In applied studies, the freshwater GIS will be an integral tool for EEA's biodiversity inventory of the southern Balkan peninsula, and in developing an inland fisheries management plan (including environmental impact studies) proposed by Bobori et al. (2001). For example, our GIS data records, including locations of 36 freshwater fishes considered extinct, endangered, threatened and vulnerable in Greece, can be used as guides to create refuges, off limits to further development. Secondly, the GIS is applicable in designing pre- and post-environmental impact studies in areas being considered for domestic and tourism growth. Studies by Johnson and Gage (1997), who applied GIS in studies relating landscape attributes to aquatic ecosystem structure and health and those by Griffith (2002), employing GIS techniques coupled with recent applications of remote sensing to landscape-water quality studies, might serve as prototypes for future studies in Greece.

Mediterranean climate, archaeology, varied aquatic and terrestrial landscapes, and the natural environment's rich biodiversity in Greece have supported economic growth and tourism in the country (Bobori et al., 2001). Without a national action plan that links terrestrial and aquatic environmental health to economic development, much of the biodiversity, integral to attracting tourists, may be lost before a GIS and gap analysis of all aquatic resources can be completed and applied to a policy of sustainable growth.

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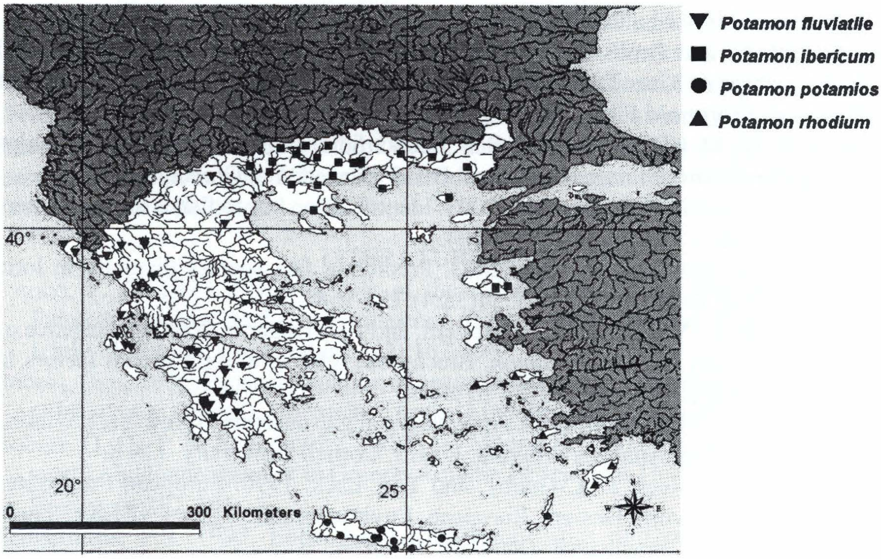

FIGURE 2. Distribution of species of *Potamon* in Greece from collections of Aristotle University and Science Museum of Virginia.

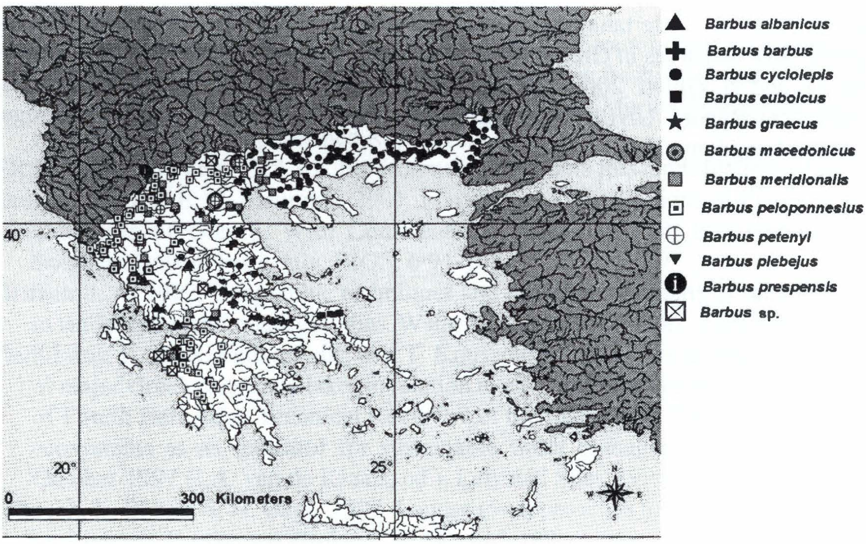

FIGURE 3. Distribution of species of *Barbus* in Greece from collections of Aristotle University and Science Museum of Virginia.

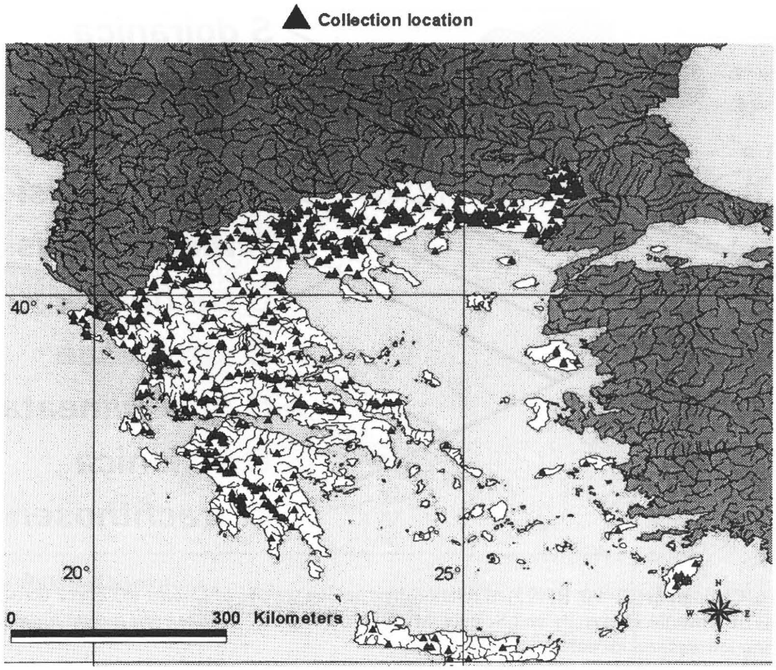

FIGURE 4. Distribution of collection locations of freshwater crabs and fishes from Aristotle University and Science Museum of Virginia.

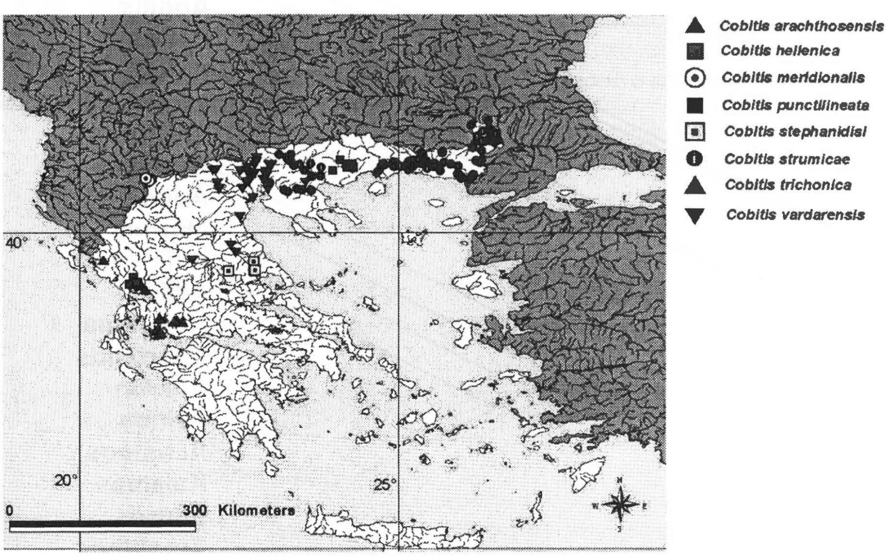

FIGURE 5. Distribution of species of *Cobitis* in Greece from collections of Aristotle University and Science Museum of Virginia.

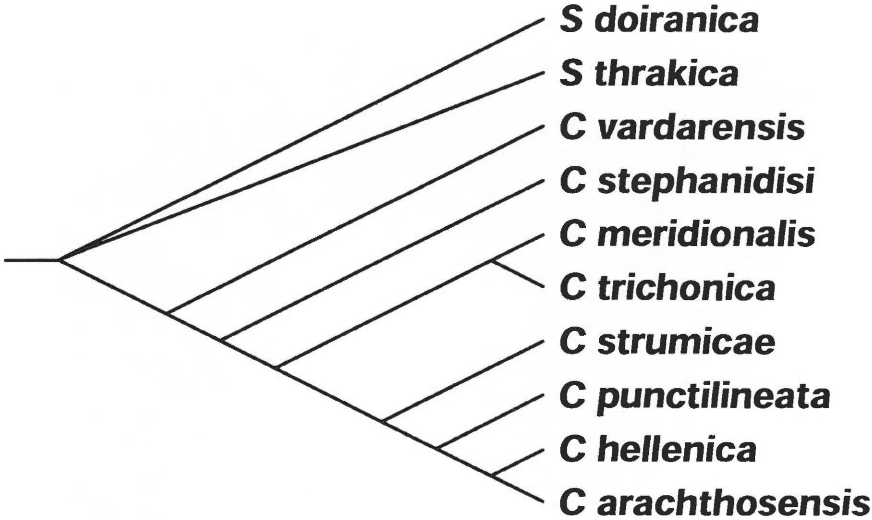

FIGURE 6. Cladogram (CI=90; RI=95) of relationships among species of *Cobitis* in Greece derived from collections of Aristotle University and Science Museum of Virginia. *Sabanejewia aurata doiranica* and *Sabanejewia aurata thrakica* comprise the out-group.

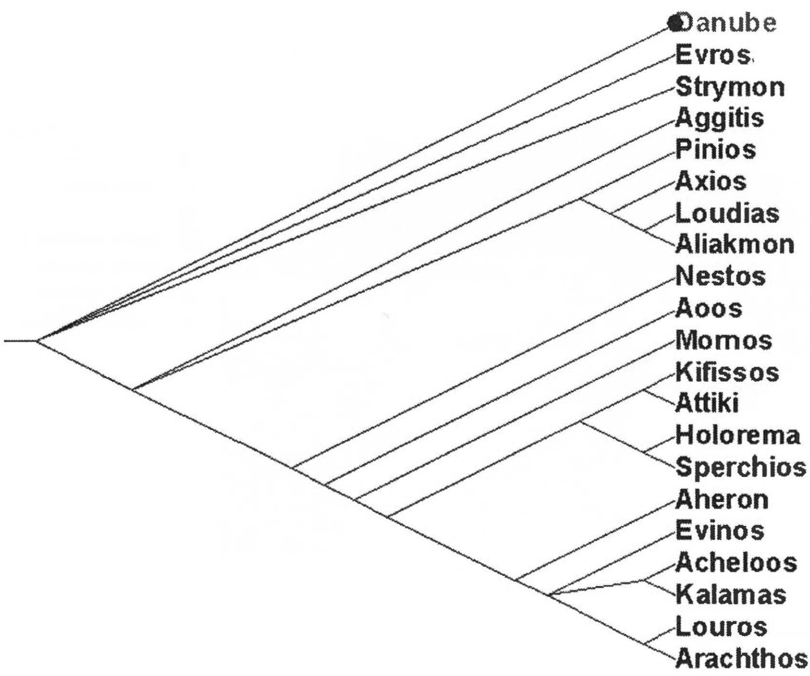

FIGURE 7. Cladogram (CI=90; RI=95) of relationships of major river drainages of mainland Greece adapted from Maurakis et al. (2001). Danube River is out-group.

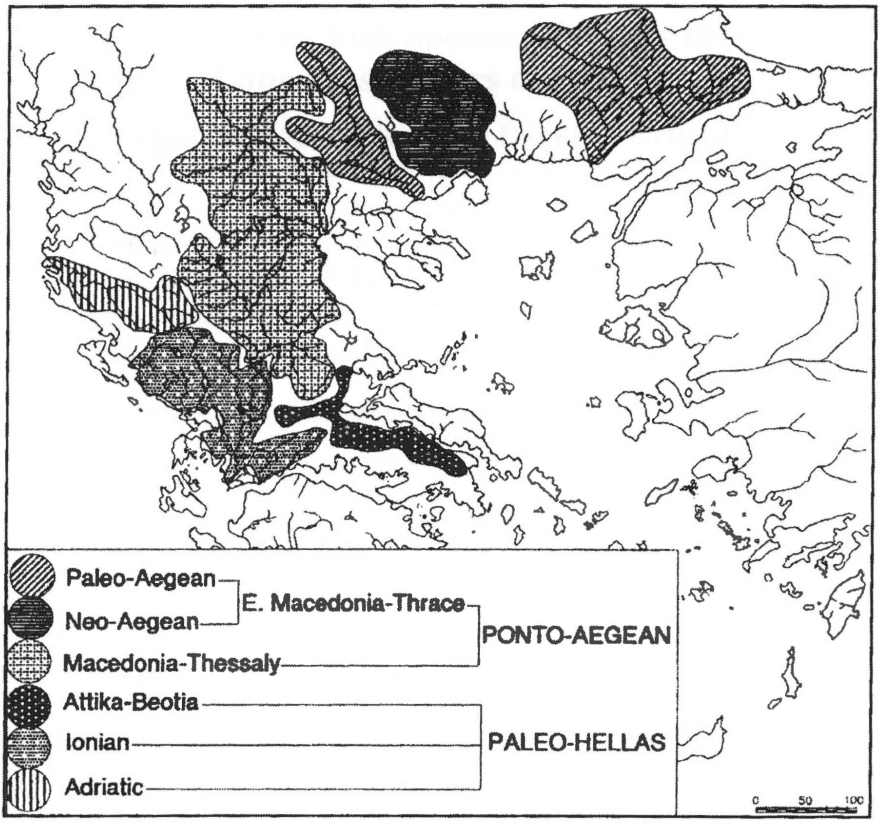

FIGURE 8. Biogeographic divisions derived from relationships of major river drainages on mainland Greece adapted from Maurakis et al. (2001).