GAP ANALYSIS REVEALED A MODERATE EFFICIENCY OF PROTECTED AREAS FOR THE CONSERVATION OF THE ENDANGERED NOBLE CRAYFISH IN CROATIA

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The noble crayfish is a native European freshwater species, endangered due to the strong anthropogenic influence on its habitats, climate change, and invasive crayfish species. In the present study, we aimed to assess the effectiveness of nationally designated protected areas and the pan-European Natura 2000 network in representing and maintaining over time the noble crayfish diversity using a comprehensive species occurrence dataset. Overall, our gap analysis indicated moderate efficiency of the existing protected areas in covering the noble crayfish diversity. Overlapping the distribution map of the noble crayfish with the map of protected areas revealed that protected areas encompass 50% of recorded populations. This study can serve as an evaluation of the protected areas in conservation of this key freshwater crayfish species.

Key words: *Astacus astacus*, Astacidae, Natura 2000 network, conservation planning, biodiversity conservation

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Plemeniti ili riječni rak je autohtona europska vrsta slatkovodnih rakova, ugrožena mnogobrojnim antropogenim pritiscima na njegova staništa, klimatskim promjenama i stranim invazivnim vrstama rakova. Cilj ovog istraživanja je bio procijeniti učinkovitost zaštićenih područja i pan-europske mreže Natura 2000 u očuvanju raznolikosti plemenitog raka u Hrvatskoj. U tu svrhu korišteni su podaci o rasprostranjenosti vrste u slatkovodnim ekosustavima Hrvatske koji su preklopljeni s kartom zaštićenih područja što je poslužilo u gap analizi. Rezultati analize su pokazali da su populacije plemenitog raka umjereno dobro pokrivene zaštićenim područjima. Preklapanjem mape zaštićenih područja s mapom nalaza rakova zaključeno je da je 50% populacija plemenitog raka unutar zaštićenih područja. Rezultati ovog istraživanja mogu poslužiti u izradi budućih planova upravljanja ovom ugroženom vrstom.

Ključne riječi: *Astacus astacus*, Astacidae, Natura 2000, konzervacijski planovi, zaštita bioraznolikosti

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INTRODUCTION

Freshwater ecosystems around the world have been critically imperilled, mostly due to growing anthropogenic pressure that negatively influence their biodiversity, and consequently led to major population declines in freshwater species (Strayer & Dudgeon, 2010). Currently, one in three freshwater species is threatened with extinction worldwide, and crayfish are among the most endangered groups (Collen *et al*., 2014). Concurrently, crayfish are recognised as ecosystem engineers and keystone species due to their high impact on freshwater ecosystems and their biodiversity (Reynolds *et al*., 2013).

The noble crayfish, *Astacus astacus*, is a widely distributed native European freshwater species (Kouba *et al*., 2014). In Croatia, it is recorded in all three biogeographical regions (Continental, Alpine and Mediterranean), and naturally distributed in the waterbodies of the Black Sea drainage, with a few recorded populations in the Adriatic Sea drainage that are of anthropogenic origin (Maguire *et al*., 2018). Currently, the noble crayfish is endangered due to the strong anthropogenic influence on its habitats, climate change, and spreading of non-indigenous invasive crayfish species and their pathogens (Jussila *et al*., 2021). European-wide population declines resulted in a protection of the species under IUCN Red List of Threatened Species (Edsman *et al*., 2010) and EU Habitat Directive (Annex III of the Bern Convention, Annex V of Habitat Directive (92/43/EEC)). In Croatia, comparison of its previous and current distributional data, in the overlapping localities, revealed that 55% of the populations disappeared during the last decades (Maguire *et al*., 2011, 2018). According to the Croatian National Red List of freshwater crayfish, it is recognised as vulnerable with decreasing population trends (Gottstein *et al*., 2011), and is protected by the Croatian Law of Nature Protection (NN 80/13). The conservation status of the noble crayfish, as assessed within the framework of the EC Habitats Directive (Council of the European Communities, 1992), was noted as 'unfavourable-inadequate' in all three biogeographical regions in Croatia (Ministry of Environmental Protection and Energy, 2019). This is the second worst possible conservation status under Article 17 of the Directive, based on four parameters: range, population, habitat of species and future prospects. According to this status, 'a change in management or policy is required to return the habitat type or species to favourable status, but there is no danger of extinction in the foreseeable future'.

Previous genetic studies revealed that Croatian populations of the noble crayfish constitute an important part of within-species genetic diversity (Gross *et al*., 2021; Lovrenčić *et al*., under review). At the same time, species distribution models forecasted substantial reductions in its habitat suitability by the end of this century. Namely, 87% of the currently suitable habitat is predicted to be lost by the 2070 time-period under the high-emissions 'RCP8.5' global warming scenario (Lovrenčić *et al*., under review). Bearing in mind that most of the populations with high genetic diversity are located in the areas predicted to become unsuitable, estimated reduction in habitat suitability entails potential loss of a significant portion of the noble crayfish genetic variability. This raises a question of how much of its diversity is actually covered by some level of protection. Since the prime task for the conservation is to secure the long-term survival of species, it is important to evaluate the extent to which existing protected areas in Croatia conserve the noble crayfish diversity.

In Europe, the cornerstone of conservation has been the Natura 2000 network. Natura 2000 is designated to support the long-term survival of the important habitats and species throughout Europe, maintaining listed habitat and species at ''favourable conservation status''(European Commission, 2000). In Croatia, the implementation of Natura 2000 led to the rise in the quantity of the conservation areas, which previously covered 9.3% of the Croatian territory. Currently, Croatia has one of the most extensive Natura 2000 networks in Europe covering 36.7% of the country and 15.4% of the seashore.

Here we assess the effectiveness of both national protected areas and the pan-European Natura 2000 network in representing and maintaining long-term survival of the noble crayfish diversity using a comprehensive species occurrence dataset. The aims of our study were to (1) overlap the distribution map of the noble crayfish with the national protected areas and Natura 2000 network in order to   reveal the effectiveness of the protected areas in safeguarding the noble crayfish, and (2) evaluate if the effectiveness of the protected areas varies between biogeographical regions. In order to achieve our goals, we performed gap analysis, a GIS-based approach that overlays species distribution data onto a map of protected areas aiming to assess the effectiveness of protected areas in preserving species diversity (Jennings, 2000; Rodrigues et al., 2004).

MATERIAL AND METHODS

Study area

Study area is located in Croatia, a country recognised as one of the hot spots of the noble crayfish diversity. It encompasses the distribution of the noble crayfish in three biogeographical regions in Croatia: Continental, Alpine and Mediterranean. Those regions cover freshwater habitats belonging to the Black Sea drainage, and also the Adriatic Sea drainage, where the noble crayfish was introduced (Maguire et al., 2018). Characteristic habitat of the noble crayfish in the study area includes rivers, streams and lakes with loam, sand or gravel bottom, where shelter availability is high. The noble crayfish prefers water with high oxygen level, and soft banks where they construct simple burrows for the shelters.

Species distribution data

Research was performed on the data from previously published work on the distribution of the noble crayfish in Croatia (Maguire & Gottstein-Matočec, 2004; Maguire et al., 2011, 2018; Gross et al., 2021; Lovrenčić et al., under review). Geographic Information System (ArcGIS) was used for preparation of distribution data (i.e. the point occurrences) of each noble crayfish population.

Gap Analysis

We performed the gap analysis, a GIS-based approach for 'assessing the effectiveness of protected areas in representing species diversity' (Rodrigues et al., 2004), by comparing the distribution of the noble crayfish with the extent of the protected area in Croatia. Gap analysis represents well-established conservation tool for the identifi-

cation of the areas in which selected elements of biodiversity (e.g., species, habitats, ecosystems) are represented, and through comparison with existing protected areas recognises areas/regions that require additional protection. Precisely, we performed gap analysis to assess how many of the noble crayfish populations are covered by protected areas (Special Protection Areas (SPAs) designated under the Birds Directive 2009/147/EC, Special Areas of Conservation (SACs) designated under the Habitats Directive 1992/43/EEC), and national and regional parks). We computed the number of populations that were included or excluded from such areas in order to detect populations and areas that need greater attention. In the gap analysis, the species/populations is considered as 'covered' if any protected area overlapped with its recorded distribution, and otherwise to be a 'gap species/population' (Rodrigues *et al*., 2004). ArcGIS program package was used to overlap occurrence data with the map of protected areas obtained from the online platform Bioportal (http://www.bioportal.hr). Upon processing and overlapping layers, a single layer was produced, and it was used to calculate the number and the percentage of populations covered by protected areas.

RESULTS AND DISCUSSION

Overlap of the noble crayfish distribution and protected areas

Results presented in this study introduce, according to our best knowledge, the first gap analysis of the noble crayfish. Thus, they can be used as an evaluation of the protected areas in conservation of this key freshwater crayfish species. Gap analysis including a total of 164 populations indicated moderate efficiency of protected areas in covering the noble crayfish diversity (Fig. 1, Tab. 1). Overlapping the distribution map of the noble crayfish with the map of protected areas revealed that 83 populations (51%) were covered, while 81 (49%) were located outside the existing protected areas (Fig. 1, Tab. 1). The coverage gaps varied across different biogeographical regions. The biogeographical region with the highest percentage of coverage (34 out of 36 populations; 94%) was Alpine since in this region numerous areas are under protection. In contrast, the Continental region that represents an important area with high noble crayfish presence exhibited the lowest coverage (42 populations are within (36%), and 74 outside (64%) protected areas) (Tab. 1). This region embodies the natural distribution area of the noble crayfish in Croatia, and thus it harbours populations with the greatest genetic diversity on mitochondrial and nuclear level (Gross *et al*., 2021; Lovrenčić *et al*., under review). Since various human activities, pollution, habitat degradation and fragmentation are progressing, this region needs special attention in future conservation management and planning. In the Mediterranean region, into which noble crayfish was introduced, 7 out of 12 populations (58%) are distributed within protected areas.

How well protected areas safeguard the endangered noble crayfish in Croatia?

Representation of species and ecosystems in protected areas, and conservation strategies is a core principle of global conservation priority setting approaches (Rodrigues *et al*., 2004). Our study revealed that the current protected areas in Croatia

(Natura 2000 network, national and regional parks) partially encompass the areas with high diversity of the noble crayfish, and in that sense, provide moderate level of protection (Fig. 1, Tab. 1). As revealed in the gap analysis, there are coverage gaps in the conservation of the noble crayfish, particularly in the habitats of the Continental region in Croatia. Contrary, study by Lovrenčić *et al.* (2020) that evaluated representation of the stone crayfish (*Austropotamobius torrentium*) by protected areas in Croatia, revealed its much greater coverage compared to the results of this study. The effectiveness of the protected areas, especially Natura 2000 network, in fulfilling their
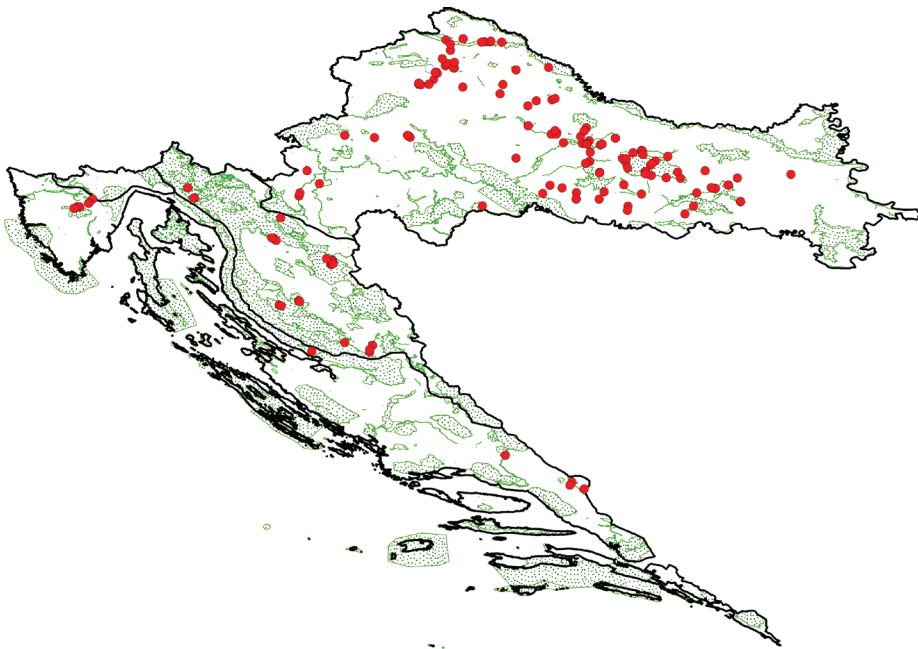
Fig. 1. Distribution map of recorded noble crayfish populations in Croatia overlapped with the protected areas. Protected areas include Special Protection Areas (SPAs) designated under the Birds Directive 2009/147/EC, Special Areas of Conservation (SACs) designated under the Habitats Directive 1992/43/EEC), and national and regional parks. Red circles represent distribution data, while protected areas are shown in green doted surfaces. Also black lines represent borders of/between biogeographical regions.

Tab. 1. Number of the noble crayfish populations per each biogeographical region when overlapped with the map of protected areas in Croatia. Protected areas include Special Protection Areas (SPAs) designated under the Birds Directive 2009/147/EC, Special Areas of Conservation (SACs) designated under the Habitats Directive 1992/43/EEC), and national and regional parks.

Biogeographical region	Within protected areas	Outside protected areas	Total
Mediterranean	7 (58.3%)	5 (41.7%)	12
Alpine	34 (94.5%)	2 (5.5%)	36
Continental	42 (36.2%)	74 (63.8%)	116
Total	83 (50.6%)	81 (49.4%)	164

role of protecting biodiversity has been evaluated through gap analysis in numerous studies at global or regional scales with the varying outcomes (Rodrigues *et al.*, 2004; Verovnik *et al.*, 2011; Gruber *et al.*, 2012; Bagella *et al.*, 2013; Abellan & Sanchez-Fernandez, 2015; Maiorano *et al.*, 2015; Orlikowska *et al.*, 2016; Yang *et al.*, 2020; Ahmadi *et al.*, 2020; Spiliopoulou *et al.*, 2021). Some studies reported great effectiveness of protected areas and/or Natura 2000 in safeguarding various groups on the European level, such as butterflies (Verovnik *et al.*, 2011), birds of prey (Mazaris *et al.*, 2013), plants (Fois *et al.*, 2017), and freshwater crayfish (Lovrenčić *et al.*, 2020). In contrast, others revealed numerous gaps in the existing networks of protected areas making them inadequate for the long-term preservation of biodiversity, as found for terrestrial vertebrates in Italy (Maiorano *et al.*, 2006, 2015), birds in tropical Andes (O'dea *et al.*, 2006), endangered flora of Almería (Mendoza-Fernandez *et al.*, 2009), European wetland species (Jantke *et al.*, 2011), and endemic species in Mediterranean temporary freshwater habitats (Bagella *et al.*, 2013).

Freshwaters in Croatia, which belong to the Mediterranean biodiversity hotspot, are characterised by high levels of diversity and endemism, but at the same time exposed to higher levels of threat than the rest of Europe (Médail & Quézel 1999; Myers *et al.*, 2000). Moreover, a study by Carrizo *et al.* (2017) showed that many Natura 2000 sites in freshwater ecosystems of southern and eastern Europe are managed poorly, with the current level of protection not being sufficient. Therefore, the effectiveness of the national protected areas and the Natura 2000 network should be enhanced by better local management of both native and invasive species, habitat restoration, public acceptance and engagement, collaboration among local and state agencies, researchers, as well as landholders and funding bodies (Blicharska *et al.*, 2016; Carrizo *et al.*, 2017).

CONCLUSION

Our results exhibited moderate efficiency of protected areas in Croatia in covering the noble crayfish distribution, and thus its diversity. About 50% of the noble crayfish populations were covered by some of the national protected areas. The percentage of covered populations varied among biogeographical regions; the best covered was Alpine region (94%), then the Mediterranean region (58%), and the least covered was Continental region (36%). We propose that, in order to achieve better and effective conservation of the noble crayfish, other available approaches, such as habitat restoration, enhancing local management, raising public awareness through local campaigns, should be included in future management plans and actions for this vulnerable species.

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