A MIGRATION GAME MODEL FOR HABITAT CONNECTIVITY OF HIGHLY MIGRATORY SPECIES

Patrizio Mariani [1]*, Vlastimil Krivan [2], Brian MacKenzie [1] and Christian Mullon [3]
[1] Technical University of Denmark, National Institute for Aquatic Resources, Denmark - pat@aqua.dtu.dk
[2] Department of Mathematics and Biomathematics, Faculty of Science, University of South Bohemia, Czech Republic
[3] Institute for Research and Development, IRD, France

Abstract

A migration game model is suggested to resolve adaptive migration in direction of increasing fitness over a complex global network of distant habitats. Many factors contribute to the migration process of highly migratory species and of primary importance are individual and collective dynamics regulating intra-specific competition and habitat selection processes. When applied to the Atlantic bluefin tuna the model predicts patterns of migration resembling those commonly observed for this species and predicts new migratory routes under future climate change scenarios. The resulting dispersal and migration dynamics can affect connectivity between distant habitats having implications for future fishery management and conservation of the species.

Keywords: Tuna, Habitat, Migration, Mediterranean Sea, North Atlantic

Movement of organisms is a widespread phenomenon in nature and it happens at all scales from bacteria moving in chemical gradients, to plankton searching for food and mates, to fish and birds travelling thousands of kilometers between distant habitats. The behavioral traits regulating movement and the ability of marine organisms to perform long distant migrations are largely unknown but when moving in large groups, are likely dependent on a balance between individual preferences and collective decisions processes. Feeding and spawning migrations between widely separated but geographically stable locations raise several questions on the ability of species moving in groups or in isolation to store information on often-complex routes as well as on the level of adaptation of the individuals to environmental changes and anthropogenic pressures.

It has been hypothesized that collective memory, transmission of social information and decision-making processes might all play an important role in migratory behavior for a large range of fish species and can regulate connectivity between distant habitats [1, 2]. Moreover, fitness based arguments are commonly used to describe the process of habitat selection in migrating populations. When moving between different habitats, individuals should prefer those sites that provide them with the highest payoff, i.e., where their fitness is maximized [3]. Nevertheless, both fitness and habitat selection typically depend on interactions among individuals, which usually have the form of a density dependent relation linking habitat quality and species distribution. Under negative density dependence, if dispersal is cost free and individuals are omniscient and free to settle at any habitat, the evolutionarily stable strategy corresponds to the ideal free distribution (IFD) [4]. At the IFD, payoffs in all occupied habitats are the same and larger or equal than those in the unoccupied habitats. Thus, no individual can improve its fitness by choosing a different habitat. Difference in competitive ability of the individuals, as well as constrains in habitat connectivity imposed by geographical (e.g., topography) or temporal (e.g., seasons) patterns can however prevent the applications of IFD theory to species performing long distance migrations.

A migration game approach has been suggested for those species migrating in a complex network of connected habitats subject to seasonal changes [5]. The approach describes population-migration dynamics in age-structured populations and in temporally varying environments and is able to predict species distribution and migratory routes for a large range of organisms.

When used to describe the seasonal migration of the Atlantic bluefin tuna, results show how changes in the resource level, population demography and cost of migration, can alter population distribution across large distances [5]. The model can also simulate future scenarios of migrations (Figure 1). Using values of habitats payoffs derived from climate models simulating tuna habitat index [6] the migration game predicts that only some subsets of the available routes on the network are effectively selected as migratory pathways, while many other routes are not utilized (Figure 1a). Moreover, the model predicts the emergence of new migration routes in the future, in particular towards Greenland and the recover of a lost historical migration route towards the northern North Sea (Figure 1b).

Bluefin tuna is a highly migratory species, and migrates across ocean zoning boundaries of several jurisdictions, and also across stock management boundaries, migration models that quantify rates and timing of exchanges among areas could potentially have practical application in fishery management and conservation.

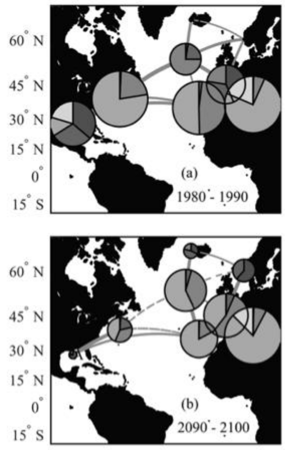

Fig. 1. Predicted distribution of bluefin tuna biomasses and migration routes between North Atlantic habitats in the period (a) 1980 – 1990 and (b) 2090 – 2100. Different age classes have different colors: from young of the year (light gray) to mature large individuals (dark gray). Connection lines indicate migration routes; dashed line are available route not used for migration.

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