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Ideal free distribution or dynamic game? An agent-based simulation study of trawling strategies with varying information

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Abstract

An ecological economic model of trawling is presented to demonstrate the effect of trawling location choice strategy on net input (rate of economic gain of fish caught per time spent less costs). Fishing location choice is considered to be a dynamic process whereby trawlers chose from among a repertoire of plastic strategies that they modify if their gains fall below a fixed proportion of the mean gains of the fleet as a whole. The distribution of fishing across different areas of a fishery follows an approximate ideal free distribution (IFD) with varying noise due to uncertainty. The least-productive areas are not utilised because initial net input never reaches the mean yield of better areas subject to competitive exploitation. In cases, where there is a weak temporal autocorrelation between fish stocks in a specific location, a plastic strategy of local translocation between trawls mixed with longer-range translocation increases realised input. The trawler can change its translocation strategy in the light of information about recent trawling success compared to its long-term average but, in contrast to predictions of the Marginal Value Theorem (MVT) model, does not know for certain what it will find by moving, so may need to sample new patches. The combination of the two types of translocation mirrored beam-trawling strategies used by the Dutch fleet and the resultant distribution of trawling effort is confirmed by analysis of historical effort distribution of British otter trawling fleets in the North Sea. Fisheries exploitation represents an area where dynamic agent-based adaptive models may be a better representation of the economic dynamics of a fleet than classically inspired optimisation models.

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1. Introduction

The management of fish stocks needs to take into account both the biological aspects of the fish population and the behaviour of the fishers themselves. Fishing behaviour incorporates aspects of economics, sociology and information science. A failure to understand these aspects of fisheries management can lead to disastrous breakdowns in the fisheries management system [1].

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There are two different approaches to understand the interactions between fishing vessels and marine resources. The top-down or classical approach seeks to explain trawler behaviour by positing relationships between resources and trawling patterns, and the bottom–up approach posits that patterns are best explained by considering how they emerge from interactions between the strategies of the individual and marine resources. The two approaches are complementary rather than contradictory (in an analogous manner to classical and quantum thermodynamics).

One fundamental relationship that has been used to explain the distribution of fishing effort [2,3] is the Ideal Free Distribution (IFD) model [4]. In this model, there is an explicit relationship between the rate of input (I_j) of a resource into an assemblage of areas and the number of consumers consuming in that area (n_j). Considering two patches: $j = 1,2$

$$\frac{n_1}{n_2} = \frac{I_1^{\alpha}}{I_2^{\alpha}}, \tag{1}$$

where α is the exponent of interference, and the subscript denotes the area on which the consumers are feeding. In the simplest case of the IFD, $\alpha = 1$ and the relationship between the ratios of n_j and I_j in the two areas is linear. This unitary case occurs when a fixed resource is divided equally between consumers.

In many cases, including here, α can be derived from the mechanics of foraging and resource replenishment. A variant on the IFD occurs when travel costs are taken into account, i.e., the distribution is not completely free [5]. Further variants occur when there are perceptual constraints, i.e., the model is not completely ideal and when competitive abilities differ between consumers [6]. A more general distribution model is described by Farnsworth and Beecham [7]. Experimental tests with animals have tended to reveal departures from the IFD, with a tendency for occupation of the better patches [8,9].

An alternative approach to understanding forager-resource distributions uses game theory. Where there are N foragers, each is expected to choose, sequentially, one of M areas, whose resources they share with others in that area, always ensuring that the area chosen gives the best return. When there are many more foragers than patches, the Nash equilibrium results in an intake per patch that is almost identical for all foragers. But when N is only slightly greater then M and the number of occupants of each patch must be quantised to a whole number of occupants, so some individuals will fare worse than others. In such a case, there may be systematic differences in patch choice between animals of different competitive abilities [6]. One pertinent objection in the case of biological systems is that the agents themselves are not able to understand the function which must be optimised, which necessarily includes many other agents and biological processes. From the standpoint of the individual, the problem is formally incomputable. However, the IFD can be achieved by relatively simple switching rules; e.g., Milinski [10] showed that a simple comparison with experience could lead to an IFD in sticklebacks. Maynard Smith [11] argued that a learning system that could cope with change necessarily involved sampling of seemingly unattractive patches. Thuusman et al. [12] showed that sampling rules that led to an IFD and a Pareto optimum for large populations led to a departure from that optimum for individuals. In the case where the IFD results from learning, it should be considered as an emergent or teleonomic property of foraging choice rather than a mechanistic solution to a foraging problem. In essence, there are two ways of looking at the distribution of vessels, as a paradigm involving assessment of the situation and active choice by the fishermen (the 'ideal' in 'IFD') and as an emergent property of a system where the information available to the trawlers is less complete.

There is a similar dichotomy in approaches between classical and agent-based economic models. In neo-classical economic models, from which the IFD model draws its inspiration, there is an implicit assumption of rationality [13]. By contrast, economic models inspired by statistical mechanics have assumed that the rationality is bounded by the information available to each agent. Such models include the El Farol problem [14] and Minority Game [15,16]. They predict that the system will attain a statistical equilibrium around which every state transition decreases payoff from an assemblage of agents with incomplete information. This information is historical and agents cannot pre-empt the decisions of their competitors. This is a much more compelling paradigm for the problem of resource uses by competing fishers than one that assumes rationality. In particular, it agrees with data from surveys of fishers, which showed that previous location of trawling was the most important predictor of subsequent trawling activity [17].