Journal of Experimental Marine Biology and Ecology 461 (2014) 179–184

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

Depth preference in released juvenile turbot *Psetta maxima*

Christoffer Moesgaard Albertsen *, Josianne G. Støttrup, Anders Nielsen, Mads O. Christoffersen

Technical University of Denmark, National Institute of Aquatic Resources, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark

ARTICLE INFO

Article history:
Received 9 April 2014
Received in revised form 25 July 2014
Accepted 26 July 2014
Available online xxxx

Keywords:
Flatfish
Migration modelling
PIT-tags
Released fish
Site fidelity

ABSTRACT

Hatchery-reared juvenile turbot *Psetta maxima* were tagged with Passive Integrated Transponder (PIT) tags and released at three different depths in a sandy bay in Denmark. About 2–7% of the released fish were registered daily to monitor their distribution using a tag antenna mounted on a modified beam trawl, thus avoiding actually sampling the fish. The change in distribution of the three groups was adequately represented by a two-dimensional movement model. Movement along the shore was described by a Brownian motion with group specific drift. Movement perpendicular to the shore line was described by a Cox–Ingersoll–Ross process with a group specific attraction point. All three groups exhibited similar depth preferences of 1.7 m. Immediately after the release, fish were concentrated around the release points but after one day, fish had moved to the preferred depth and subsequently maintained their position at this depth. Farmed turbot exhibited strong site fidelity and an innate behaviour for selecting a preferred depth.

1. Introduction

Flatfish (Pleuronectiformes) juveniles are commonly concentrated in shallow waters indicating that water depth plays an important role in their distribution. These coastal nursery habitats provide good foraging opportunity, low predation risk, higher temperatures, and appropriate substrata (Burrows et al., 1994; Kramer, 1991; Neuman and Able, 1998; Vanderveer et al., 1991). Settlement of flatfish in shallow nursery areas is established after transport of larvae to these areas from the spawning grounds. Once settled, turbot *Psetta maxima*, brill *Scophthalmus rhombus*, and flounder *Platichthys flesus* exhibit highly restricted depth distribution (0–3 m) during the early juvenile stage (Gibson, 1994).

Plaice *Pleuronectes platessa* (Burrows et al., 1994) and turbot (Sparrevohn et al., 2002) reveal strong site fidelity within their restricted shallow depth range. For plaice this site fidelity is largely maintained during the daytime (Gibson, 1973) whereas they move inshore during nighttime (Burrows et al., 2001). Released turbot in a microtidal area showed an alongshore displacement within the same depth with the directional movement related to the direction of local wind-driven currents (Sparrevohn et al., 2002). This restricted habitat use during the juvenile stage strongly influences the recruitment potential of the species (Gibson, 1994). If the size of the nursery area is reduced, for example because of negative impact from human activities, numbers of juvenile flatfishes would not compensate by increasing their densities, and the total stock would be reduced (Zijlstra, 1972).

Selecting the most suitable habitat for the release of farmed fish is an important determinant for the success of a release, which is measured by the survival of the released individuals and their contribution to the natural recruitment of the adult population. A suitable habitat is thus a combination of location and sufficient area of the preferred depth of the species. However, it may not always be possible to release fish at their ideal depth due to either limited access by land, for example, where fish were released directly from a truck on board a ferry in deeper depths (≥6 m; Støttrup et al., 2002) or without access to smaller vessels, for example, where the fish were released directly from the shore line using waders (≤1 m; Sparrevohn et al., 2002). Differences in environmental conditions with depth may affect diet, diel and tidal migration patterns in tidal areas (Burrows, 1994) and growth (Rountree and Able, 1992; Sparrevohn and Støttrup, 2008). If the farmed fish are unable to make their way to the optimal depths, the success of the release may be negatively impacted.

A simple way to describe small-scale movement of fish is to apply diffusion theory, where each individual fish displays Brownian motion and moves independently of conspecifics. A one-dimensional model was applied successfully to the released turbot to describe alongshore movement or displacement which was related to directional wind-driven currents (Sparrevohn et al., 2002). In this study, we wished to go one step further and quantify fish movement in two directions, thus enabling the study of depth preference in juvenile turbot. The Cox–Ingersoll–Ross process limits movement variability when the fish are close to the shore which, along with an incorporated preference parameter, drives them away from the shore. When the fish are far from the shore, they are modelled to move more freely but with a long term depth preference. These qualities make the process suitable for modelling movement perpendicular to the coast.

* Corresponding author. Tel.: +45 24480992.
E-mail address: cmoe@aqua.dtu.dk (C.M. Albertsen).

http://dx.doi.org/10.1016/j.jembe.2014.07.013
0022-0981/

A field experiment was conducted to examine whether naïve turbot exhibit depth preference. For quantification, a two-dimensional model was developed to describe this small-scale movement, including the speed with which the turbot sought their preferred depth, and whether or not they maintained their position subsequently (site fidelity).

2. Materials and methods

2.1. Location and experimental design

Begtrup Vig is a small bay near Aarhus, Denmark (Fig. 1). Because of its sandy bottom, limited exposure to wind and isobaths parallel to the coast it was chosen as the site for this experiment. Reared one-year old turbot (average size: 14.2 cm, range: 11–19 cm), were purchased from a commercial fish farm and were tagged with individually identifiable PIT tags (length: 23 mm, diameter: 3.65 mm, weight: 0.6 g). A total of 694 fish were divided into three groups and released (231 fish released at depth of 1 m, 231 at 3 m, 232 at 5 m) at 20:30 h ($t = 0$).

Starting the day after the release and continuing for five consecutive days, the release area was trawled in multiple directions with a modified 2 m beam trawl (without net) and mounted with a PIT tag antenna (Sparrevohn et al., 2014, width: 186 cm) and a dive computer. Two 8.8 kg blocks were mounted on the trawl to keep it on the seabed. On the first day, the equipment was calibrated in the morning, and subsequently trawls were performed in the afternoon. On the following days the area was trawled during the entire day.

Positional data were registered by the Humminbird navigational system on the boat at each directional change. Depth data were registered by both the Humminbird and the dive computer. Additionally the dive computer recorded temperature data.

2.2. Model and data handling

The model is setup to mimic the location and the experiment. The movement model is two-dimensional and the two movement directions are modelled independently, which is based on the observation that the bathymetry curves are parallel to the shore line in the study area. The movement along the shore is assumed to follow a Brownian motion with drift and diffusion. For the movement perpendicular to the shore line a Cox–Ingersoll–Ross is assumed. A Cox–Ingersoll–Ross process has an attraction point (here used to model preferred depth) and its diffusion part decreases when the distance to the shore line becomes small, which realistically ensures that the fish only move in the water. The observations are modelled by taking the scanner tracks into account, and modelling the probability of individuals being within or outside these scanned tracks. Let $X_i(t)$ and $Y_i(t)$ denote the position parallel (x) and perpendicular (y) to the shore of the ith fish at time $t > 0$ measured in days. Assuming that the fish are independent, and that the movement in the x and y direction is independent for each fish, then the movement of each fish in the x direction is modelled by a Brownian motion

$$dX_i(t) = \alpha_{x,g(i)}dt + \sigma_x dB_i(t) \quad (1)$$

with $X_i(0) = r_{x,g(i)}$, while the movement of the fish in the y direction is modelled by a Cox–Ingersoll–Ross process

$$dY_i(t) = -\alpha_y\left(Y_i(t) - \mu_{g(i)}\right)dt + \sqrt{Y_i(t)}\sigma_y dB_i(t) \quad (2)$$

with $Y_i(0) = r_{y,g(i)}$. Here $g(i)$ is a factor mapping the number of the fish to the corresponding release group, $a_{x,g(i)} \in \mathbb{R}$, α_y, $\mu_{g(i)}$, σ_x, $\sigma_y > 0$ and $B_i(t)$ is a two dimensional standard Brownian motion where B_i is

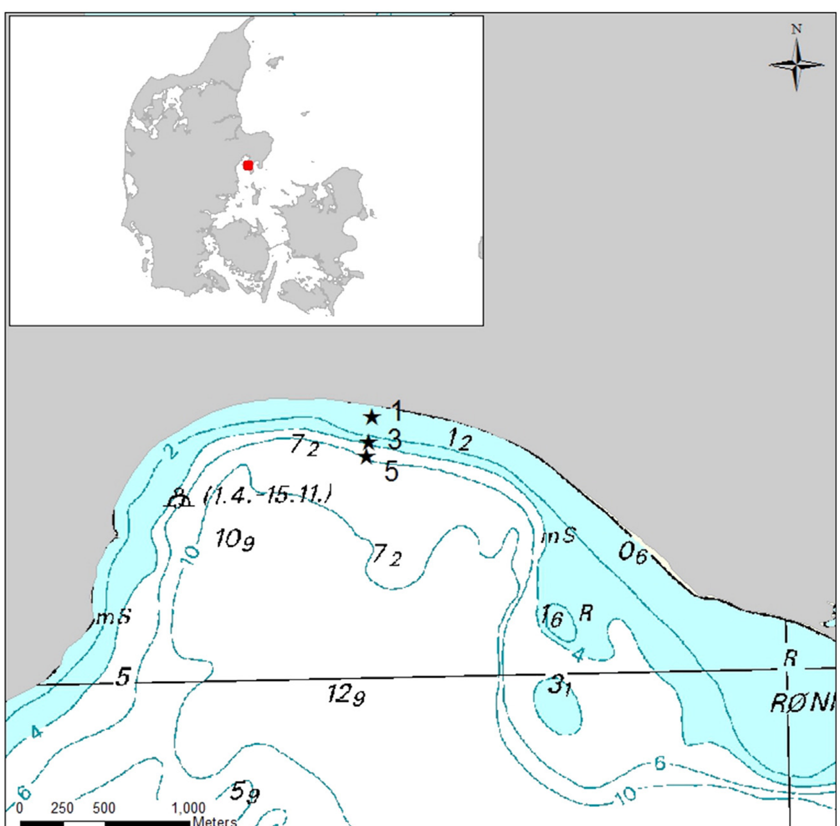

Fig. 1. Map showing the location of the turbot releases at Begtrup Vig, Denmark. Release points at 1, 3 and 5 m depth are marked with ⋆. Depth curves of 2, 4, 6, 8 and 10 metres are also shown on the sea chart.