Applying Fishing-gear Simulation Software to Better Estimate Fished Space as Fishing Effort

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Modeling fishing-gear systems is essential to better understand the factors affecting their movement and for devising strategies to control movement. In this study, we present a generalized mathematical modeling methodology to analyze fishing gear and its various components. Fishing gear can be divided into a finite number of elements that are connected with flexible lines. We use an algorithm to develop a numerical method that calculates precisely the shape and movement of the gear. Fishing-gear mathematical models have been used to develop software tools that can design and simulate dynamic movement of novel fishing-gear systems. The tool allowed us to predict the shape and motion of the gear based on changes in operation and gear design parameters. Furthermore, the tool accurately calculated the swept volume of towed gear and the surrounding volume of purse-seine gear. We analyzed the fished volume for trawl and purse-seine gear and proposed a new definition of fishing effort, incorporating the concept of fished space. This method may be useful for quantitative fishery research, which requires a good understanding of the selectivity and efficiency of fishing gear used in surveys.

Key words: Fishing gear modeling, Simulation software, Sampling gear, Fishing effort, Swept volume, Fished volume

Introduction

Fishing-gear systems consist of netting and ropes, which are flexible structures. The features of these systems are affected by various forces in ocean environments, and will change shape accordingly. This is why mathematical modeling of the fishing gear system is difficult. However, mathematical modeling of fishing-gear systems is essential to understand their movement for designing appropriate gear.

Several studies have described theoretical models for underwater flexible systems, including a fishing-gear system. These models are mathematically interpreted with the aid of advanced formulation skills, numerical calculation methods, and computer systems (Geradin and Rixen, 1997; Bessonneau and Marichal, 1998; Lee and Cha, 2002; Takagi et al., 2002; Tsukrov et al., 2002; Lee et al., 2005, 2008). Some software tools have been developed for designing and simulating the dynamic movement of fishing-gear systems (Vincent, 2001; Lee et al., 2005; Vincent and Marichal, 2005). Software tools help predict the shape and motion of the gear quantitatively in relation to operational conditions and design parameters.

Fishing effort, as an index of fishing intensity, has been calculated using the number of gear deployed and tow duration (FAO, 1993). The definition of fishing effort and associated parameters varies and is open to interpretation. However, the true fishing effort exerted on a marine ecosystem is dependent on the fished volume of the gear in the water, which has a three-dimensional configuration (Mangel et al., 2010). The latest fishing techniques aimed at maxi-
mizing fishing effort and catch performance have been achieved through improved gear design, but the method for evaluating fishing effort has not changed. We suggest that fishing effort should be evaluated differently according to the size of the fished space of the gear, such as the swept volume for towed gear and the surrounding volume for purse-seine gear. Therefore, a suitable method to accurately estimate the fishing effort of fishing gear is required that considers its working space.

The swept or surrounding volume of fishing gear, one of the most important factors influencing catch size, changes with the size and structure of the gear and the method of operation. Using simulation tools, it is possible to analyze the fished space quantitatively, considering the structure of the fishing gear and the operational conditions during fishing.

The purpose of this study was to present an evaluation method for fished space based on a mathematical analysis using simulation tools for trawl and purse seine fisheries, which are representative fishing methods in Korea. We first describe a generalized modeling method that simulates dynamic movement and fishing-gear shape. This model is then applied to simulate trawl and purse seine gear to quantitatively calculate their shapes. We then analyze the fished space for the trawl and purse seine fisheries in Korea. Finally, we discuss the definition of fishing effort, incorporating the concept of fished space for quantitative fishery resource surveys.

### Materials and Methods

#### Mathematical fishing-gear model

The theoretical model used to mathematically calculate the movement of fishing gear is the mass-spring model (Lee, 2002). It is assumed that elements constituting the gear consist of a physical system divided into mass points of finite number, connected with an elastic rope. Additional rigging parts, such as sinkers and buoys, are assumed to be mass points. The mesh number of the actual net is approximated as a small number of mass points to allow for a rapid calculation. The mathematical calculation method has been described in detail in previous studies (Lee et al., 2005) and is summarized here. The motion equation for a fishing-gear system is represented as

\[(m + \Delta m)\ddot{q} = F_{\text{int}} + F_{\text{ext}},\]  

where \(m\) is mass, \(\Delta m\) is the added mass, \(\ddot{q}\) is an unknown acceleration vector, \(F_{\text{int}}\) is the internal force being applied between the mass points, and \(F_{\text{ext}}\) is all external forces applied to the mass points.

The added mass of a mass point is given by the following:

\[\Delta m = \rho_{sw}v_NK_m,\]  

where \(\rho_{sw}\) is the density of seawater, \(v_N\) is the volume of the mass point, and \(K_m\) is the added mass coefficient, which is 1.5 because the structural connections are considered to be spheres (Takagi et al., 2004; Wakaba and Balachandar, 2007; Lee, 2009). Cylindrical structures, such as ropes, are described as

\[K_m = 1 + \sin\alpha,\]  

where \(\alpha\) is the angle of attack.

The internal force is the force that is applied to the lines connecting the mass points, and because the lines are assumed to be a spring in this study, it is the force from the elongation of the spring. The internal force applied to each mass point is

\[F_{\text{int}} = -kn(|r| - l^0),\]  

where \(k\) is the stiffness of the line constituting the fishing gear, \(n\) is the unit vector along the line of the spring, \(r\) is the position vector between the neighboring mass points, and \(|r|\) shows the magnitude of the position vector. \(l^0\) is the initial length of the spring in relation to the position vector.

\[k = \frac{EA}{l^0},\]  

where \(E\) is the elasticity modulus, and \(A\) is the effective area (i.e., actual cross-sectional area) of the material.

The external force, \(F_{\text{ext}}\), is the force that is applied to each mass point from the outside, and it consists of drag, \(F_D\), lift force, \(F_L\), buoyancy, and sinking force, \(F_R\):

\[F_{\text{ext}} = F_D + F_L + F_R,\]  

Drag and lift forces are described as follows:

\[F_D = -\frac{1}{2}C_D\rho_{sw}SU^2n_V\]  

\[F_L = \frac{1}{2}C_L\rho_{sw}SU^2n_L\]