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The effect of environmental variables, gear design and operational parameters on sinking performance of tuna purse seine setting on free-swimming schools

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ABSTRACT

There are three main types of tuna purse seine operations: setting on free-swimming schools, setting on fish aggregation devices, or setting on marine mammal associated schools. In this research, we measured sinking performance of 88 purse seine sets on free-swimming skipjack (*Katsuwonus pelamis*) schools in the western and central Pacific Ocean from October 2006 to May 2013. The sinking behavior of a purse seine is influenced by many factors (e.g. netting materials, sinker weight, length-height ratio, mesh size, purse line length, setting position, setting speed, current, wind, etc.), it may be difficult to quantify the effect these factors have on the sinking performance. A purse seine set is considered to have a better sinking performance if its purse line reaches a greater depth in a shorter time period, i.e., higher sinking speed and greater sinking depth. A generalized additive model (GAM) was used to analyze sinking depth and sinking speed under different sea conditions (current speed and direction at different layers), gear design (length-height ratio, towing line length and purse line length), and operational methods (shooting duration and setting speed). The results in this study showed that the sinking performance of a purse seine with a lower length-height ratio was better than a seine with a higher ratio, current speed at 120 m depth was the most important environmental factor affecting sinking depth of the purse seine. Sinking depth was strongly associated with length-height ratio, shooting duration and purse line length. Sinking speed was related to length-height ratio, shooting duration, current speed at 60 m, purse line length and towing line length. The sinking performance models obtained from this study can be used to predict sinking behavior in relation to operational and environmental conditions, which is essential for the success of tuna purse seine operation on free-swimming tuna schools.

1. Introduction

The tuna purse seine is one of the most advanced types of surrounding nets targeting schooling fish (Bromhead et al., 2003). Tuna schools can be classified as free-swimming schools, floating-object-associated schools (e.g. fish aggregation devices, or FADs), and large-marine-animal-associated schools (Fréon and Dagorn, 2000; Castro et al., 2002).

Compared with floating-object-associated schools, free-swimming tuna schools are more mobile, and less predictable with regard to their vertical and horizontal positions which are often influenced by environmental conditions (Hosseini et al., 2011). Before the wide spread use of FADs in the last thirty years (Arechavala-Lopez et al., 2015), free-swimming tuna schools were the main targets of purse seines. Many studies were therefore carried out to determine the relationship between success rate and environmental factors (Murphy and Niska, 1953; Green, 1967; Evans et al., 1981).

In order to protect juvenile bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*), the Western and Central Pacific Fisheries Commission (WCPFC) adopted a conservation and management measure (CMM) that prohibits setting seines on floating-object-associated (or FAD) tuna schools for two months each year in 2008, and this prohibition has been extended to four months since 2013. This increasingly stringent management trend forced all tuna purse seine

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vessels to change their fishing strategy by increasing their investment in targeting free-swimming schools. However, fishing for free-swimming tuna schools is more difficult, resulting in lower success rates (Hall and Roman, 2013; Fonteneau et al., 2010; Harley and Suter, 2007). Therefore, improving success rate of purse seine fishing on free-swimming tuna schools has become a practical and scientific issue for sustainable and conservation-oriented fishing for some species of tuna.

In terms of gear performance, the sinking behavior of the purse seine is the key factor affecting success rate of capture. A purse seine set is considered to have a better sinking performance if its purse line reaches a greater depth in a shorter time period (higher sinking speed). The faster the net sinks, the greater the chance of success (Kim et al., 2007; Hosseini et al., 2011).

Observation of sinking behavior of tuna purse seine at sea has been limited due to the large size of the net and complicated environmental conditions on the fishing grounds (Kim et al., 2007; Xu and Tang, 2016). Alternatively, many studies employed model tests and numerical simulations to understand the sinking behavior of purse seines.

Kim et al. (2007) found that a purse seine made of higher density netting sank faster than that of lower density netting. Park (1986) concluded that the current was the most important environmental factor influencing sinking speed and net geometry. Beltestad (1981) reported that a purse seine with hexagonal mesh netting sank faster than one with diamond mesh netting due to lower water resistance resulting from the larger mesh openings of hexagonal meshes when the netting plane was stretched vertically. Misund et al. (1992) analyzed sinking behavior of a mackerel purse seine with different mesh sizes, and confirmed that larger mesh sizes improved sinking performance.

In general, sinking behavior of purse seine is affected by netting material, leadline weight, mesh size, hanging ratio, mesh geometry, as well as environmental conditions and operational parameters (Kim et al., 2007). However, many previous researches only concentrated on fishing gear attributes and overlooked operational parameters (Konagaya, 1971; Xu and Tang, 2016). In addition, most previous studies on the sinking performance of purse seine gear have employed a linear analysis method (Zhou et al., 2013), which imposes restrictions on the internal relationship between the sinking performance and various factors, because there is a real situation where some factors are not linearly related to sinking performance (Tang et al., 2013). More recently focus has shifted towards understanding mechanisms for a successful set in relation to fishing gear design, operational methods and environmental parameters, all of which can influence the chance of success (Kim, 2000; Kim et al., 2007; Park, 1986).

This study explores the effect of fishing operational parameters (shooting duration, purse line length, towing line length, and setting speed) and environmental factors (current speeds and directions at different water layers), as well as gear parameters (length-height ratio) on sinking performance based on data gathered from extensive field observations of commercial tuna purse seine operations and Generalized Additive Models. The result can be used to predict and to improve sinking performance by optimizing fishing operational parameters in specific environmental conditions.

2. Material and methods

2.1. Fishing vessels and fishing gears

We conducted sea trials on board two typical Chinese tuna purse seiners (“Jinhui No. 6” and “Jinhui No. 7”); each operated a pelagic purse seine targeting skipjack tuna (*Katsuwonus pelamis*) in the Western and Central Pacific (WCPO) (Fig. 1). The main dimensions of the two purse seiners are listed in Table 1.

The purse seines used by “Jinhui No. 6” and “Jinhui No. 7” are the same in net structure and netting materials, which composed of 29 knotted braided nylon netting panels with mesh sizes from 90 mm (the bunt) to 260 mm (main body), and sinker weight of 13 kg/m in air, as showed in Fig. 2. The overall sizes of the purse seines used by the two fishing vessels are slightly different. The smaller purse seiner “Jinhui No. 6” had a float line of 1 664.5 m and a stretch depth of 311.1 m, with the length-height ratio (LHR) of 5.35. The larger purse seiner “Jinhui No. 7” had a float line of 1 637.7 m and a stretch depth of 321.6 m, with a LHR of 5.09.

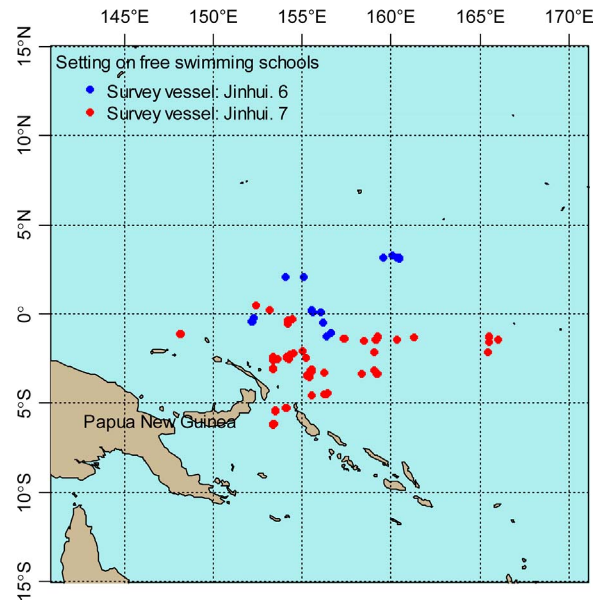

Fig. 1. Fishing location of Jinhui No. 6 (*Blue points*) and Jinhui No.7 (*red points*) in the Western and Central Pacific Ocean near Papua New Guinea.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Field measurement and data collection

A total of 88 at-sea measurements refer to the number of purse seine sets on free-swimming tuna schools were collected from October 2006 to May 2013. Sinking depth and sinking speed of the purse seines were measured with the temperature depth sensor (TDR-2 050, Richard Brancker Research Co., Ltd, Canada), with the maximum measurement depth of 740 m below surface and an accuracy of ± 0.05% (0.05% of actual depth). The TDR were 250 mm long and 40 mm in diameter, and weighed 1.156 kg in air. Seven time-synchronized sensors were attached at different positions of the purse seine leadline to monitor the depth of the main body in a recording interval of 5 s during fishing operations. We marked the position on the net structure and kept the same position each time. During hauling stage, the TDR were removed from the net and the data were downloaded to a computer. The maximum sinking depth was determined by depth variation curve from TDR. Current speeds and direction were measured at 10 m, 60 m and 120 m using a Doppler current meter (JLN-628, Japan Radio Company), a common practice for commercial fishing operations.

Other data such as shooting duration, setting speed, and towing line length and purse line length, were recorded for all fishing operations during the sea trials. Towing line is the last part of the seine that is paid out from the purse seiner, it can be used to allow a greater circumference of set to be made by using the tow line as an extension of the net. Purse line is made of steel wire rope for tuna purse seines, which is subjected to considerable frictional wear in the purse rings and abrasion on the winch barrel and in the purse blocks. The shooting duration refers to the period of time from beginning of shooting to the completion of encirclement. The setting speed was the average speed calculated from the headline length divided by the shooting duration. The towing line length and the purse line length were the products of average setting speed and the corresponding shooting duration (towing