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LITERATURE REVIEW OF FLYING FISH: BIOLOGY, DISTRIBUTION, PRODUCTION, AND CURRENT RESEARCH

Tinjauan Pustaka Ikan Terbang: Biologi, Distribusi, Produksi, dan Penelitian Terkini

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ABSTRACT

This article presents various literature related to flying fish from 1930 to the present, which are shown in the form of aspects of biology, distribution, fisheries, and utilization of Current Technology in Flying Fish Research. This study was conducted through a systematic search and review of various articles, books, dissertations, and theses that discuss flying fish. Literature studies related to flying fish are important to provide more complete information required to maintain the sustainability of their resources. This study shows the classification, type, spawning process, body shape, ability to glide in the waters, distribution, fishing technology, and current technology in various researches.

Keywords: *biology, distribution, flying fish, fisheries.*

ABSTRAK

Artikel ini menyajikan berbagai literatur terkait ikan terbang mulai dari tahun 1930 hingga sekarang. Berbagai aspek kehidupan ikan terbang dikemukakan, berupa aspek biologi, distribusi, perikanan dan pemanfaatan teknologi terkini dalam Riset Ikan Terbang. Studi ini melakukan pencarian dan tinjauan sistematis terhadap berbagai artikel, buku, disertasi dan tesis yang membahas tentang ikan terbang untuk mendukung penelitian terkait hal tersebut. Studi literatur terkait ikan terbang penting untuk dilakukan demi mendukung informasi yang lebih lengkap demi menjaga keberlanjutan sumberdayanya. Studi ini menunjukkan klasifikasi, jenis, proses pemijahan, bentuk tubuh, kemampuan meluncur di perairan, distribusi, teknologi penangkapan serta *current technology* dalam berbagai riset.

Kata kunci: biologi, distribusi, ikan terbang, perikanan

INTRODUCTION

The study of flying fish began to be published in the 1930s with a discussion of the structure of flying fish. The study also revealed that some flying fish have very large pairs of pectoral fins that allow them to glide over the surface. While others have very large pairs of pectoral and pelvic fins (Breder 1930).

Flying fish (Exocoetidae) is a small pelagic fish that lives in tropical and subtropical waters (Oxenford *et al*. 1995; Parin 2002; Saveliev *et al*. 2014). These fish are important components in the food chain, where they are prey for large pelagic fish such as marlin, tuna, skipjack and dolphins (Araujo dan Chellappa 2002; Huang and Ou 2012; Oxenford and Hunte 1999). Exocoetidae species mainly feed on copepods, followed by species from the zooplankton group including amphipods, chaetognaths, crustaceans and fish larvae (Van Noord *et al*. 2013). This causes flying fish to have a dual role as predator and prey in aquatic ecosystems.

Flying fish have the ability to fly above the surface of the water and the fish eggs have high commercial value (Uygun and Hossucu 2018). The high commercial value of flying fish and as an important component in the food chain is an important reason for management for the sustainability of these fish resources. As is well known, although fish resources are resources that can recover, if they are not managed properly the rate of exploitation may not be in line with the rate of recovery. Emperua *et al*. 2017 found that there has been a decrease in abundance which is feared to have an impact on its sustainability status in the future. Several flying fish species, namely Cypselurus poecilopterus (Valenciennes 1846), Cheilopogon spilopterus and Hirundichthys affinis (Gunther 1866) are in a state of overfishing recruitment (Gomez *et al*. 2019).

Growth and reproduction are the most important factors that play a role in increasing fish biomass (King 2007). How fast an animal grows and whether it reproduces once or twice, or more, in a single life span is part of the important information about fish life history traits used for stock status assessment, which is important for developing resource management plans (Chang *et al*. 2022). If there is no continuous information about flying fish, fishing pressure, climate change and other challenges can threaten the sustainability of the resource. Therefore, this review is important as reference material for flying fish management, as well as related research. The purpose of this research is to learn better and more deeply about various aspects of flying fish life in the form of biology, distribution, fisheries, and the latest research on flying fish. This review is essential as reference material for flying fish management, as well as related research. In addition, studies on flying fish have not been found, especially in more in-depth studies. This study tries to reveal a literature review related to various aspects of flying fish.

METHODS

Studies of flying fish species that have been carried out since 1930 have become our reference in identifying these fish. A systematic literature search of articles, books, dissertations, and theses that introduce and present various aspects of flying fish was carried out in July – December 2022 in this study. Multiple terms, languages, and names of fish species are used as references in searching for multiple abstracts, keywords, or written content related to flying fish, which is the method used in exploring the early literature until now. Search the identification of articles/papers on various publication search sites for further analysis.

The author first reviews the title and abstract to find the suitability of the search with the results obtained related to the life of flying fish in the form of biological aspects, distribution in various glasses of water, aspects of fisheries, and the latest technology used by researchers in uncovering facts related to flying fish. After selecting 57 articles that we hoped would explain various aspects of flying fish, we proceeded to the full article review stage and tabulated the ideas in the articles. After the full article review stage, we include the research results into four parts that can explain the life habits of flying fish. The classification of aspects is made based on relevant research results and complements the information obtained.

RESULTS

Studies of flying fish species that have been carried out since 1930 have become our reference in identifying these fish. A systematic literature search of articles, books, dissertations, and theses that introduce and present various aspects of flying fish was carried out in July – December 2022 in this study. Multiple terms, languages, and names of fish species are used as references in searching for multiple abstracts, keywords, or written content related to flying fish, which is

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DISCUSSION

Flying Fish Biology

The growth of flying fish is assumed to be fast-growing and short-lived fish (Mahon *et al*. 1986). The average age of flying fish is one to two years (Huang and Ou 2012). Flying fish are fish that live in groups, have a bluish skin color with a white belly. The fish has a maximum length of 21 cm (FishBase 2022). The long, broad pectoral and V-shaped caudal fins. Flying fish have an average body length of 17 cm, but some species can grow up to 40 cm (Chang *et al*. 2012b). Flying fish species Parexocoetus brachypterus is a relatively small flying fish species, adult sizes in the range of 110-130 mm (Lewis 1961). Species distribution size results from complex interactions between multiple factors, including organism characteristics, phylogenetic history, and environmental conditions (Bohning-Gaese *et al*. 2006; Gaston 2009), future investigations on flyingfishes could incorporate more of these potentially relevant variables (Lewallen *et al*. 2011).

Flying fish have adhesive filaments that hold their eggs in a mass so they can attach to the substrate in the waters (Evans 1961; Kovalevskaya 1982; Hunte *et al*. 1995). However, not all flying fish species contain filaments in their eggs (Gillette dan Ianelli 1992). Flying fish eggs have bond threads (fibers) between the eggs which function to attach to the substrate on which they nest. Objects that are often used as flying fish to lay their eggs are fronds/coconut leaves that float or on sea grass.

The breeding season for flying fish is all year round, but flying fish cannot produce eggs all the time. The peak period for flying fish eggs is generally in the middle of the year, in the Makassar Strait waters flying fish produce eggs in May-October. Flying fish have partial spawning, where spawning is done more than once during a spawning season. Spawning is thought to occur on floating bodies where mature females attach eggs (Stevens *et al.* 2003). Several studies reported that flying fish eggs stick to seaweed and floating objects (Kovalevskaya 1982). Objects that are usually attached to the eggs are coconut branches, banana leaves and other objects that float in the waters (Khokiattiwong *et al*. 2000). Fish spawning is often found in the weakest currents (Johannes 1978). This may be related to the effect of currents on the presence and abundance of eggs produced. Research shows that flying fish spawning occurs twice a year in May-June and at the end of November-December (Araujo and Chellappa 2002; Araujo *et al*. 2011; Khokiattiwong *et al*. 2000). The season period can be influenced by the surrounding climatic conditions (Oliveira *et al*. 2015). The condition of the surrounding waters affects the spawning time of fish, where generally fish can hatch their eggs in warmer conditions.

Flying fish eggs will hatch in the range of 24-36 hours after fertilization. Flying fish eggs are better known as tobiko (Japanese). Tobiko is popularly used by chefs in Japan and America in every dish, especially sushi and local caviar (Oliveira *et al*. 2015). In several countries, flying fish eggs are believed to have medicinal effects and can improve blood circulation so that flying fish eggs have high economic value (Potts *et al*. 2003, Anwar *et al.* 2019). Araujo and Chellappa (2002) reported that flying fish have an average absolute fecundity of 5400 eggs. Growth and reproduction are important factors in fishery resources. Ichimaru 2008 and Chang *et al*. 2022 estimate the hatching time of flying fish eggs at 11-15 days.

Flying fish have a streamlined torpedo-shaped body and can help them glide across the surface of the water at speeds up to 59 km/h and reach a distance of 400 m (Fish 1990; Davenport 1994; Kutschera 2005). Its gliding ability allows the fish to escape from predators, such as mackerel, tuna, swordfish and other large pelagic fish. Meanwhile, these fish can prey on small organisms such as

plankton. Classification of flying fish (Nelson 1996) as follows:

Phylum : Chordata
Superclass : Gnathostomata
Class : Osteichthyes
Subclass : Actinopterigii
Infraclass : Teleostei
Division : Euteleostei
Superorder : Acanthopterygii
Series : Atherinomorpha
Order : Atheriniformes
Suborder : Exocoetoidei
Family : Exocoetidae
Subfamily : Exocoetinae
Genus : Hirundichthys, Cypselurus, Parexocoetus, Exocoetus, Evolantia, Oxyporhampus, Fodiator, Pronichthys dan Cheilopogon.

Flying fish is a fish that has many types. According to the classification, the genus of flying fish consists of 9 types. Long pectoral fins and sheets are used by this fish to glide, even fly over the surface of the sea. The ability of these fish is a form of evolution to avoid predators. Utilizing its body shape which is like a torpedo, flying fish can accelerate in water and reach speeds of up to 59 km/h before sliding to the surface. Once in the air, flying fish will expand their broad pectoral fins to stay afloat for a long time. When crossing the surface of the waters to fly flying fish face various challenges such as continuous sunlight, lack of buoyancy and high accumulation of CO2 (Wright and Turko 2016) as amphibian fish (Xu *et al*. 2021). The refractive index of air usually affects fish to be myopic in air (Baylor and Shaw 1962). Baylor 1967 showed that flying fish have pyramidal corneas, which are responsible for hypermetropic underwater vision and emmetropic air vision.

Flying fish are classified as small pelagic fish, living at sea level 0-20 m (FishBase 2022), including fast swimmers, can be attracted by light at night. Flying fish can reach speeds of up to 30km/hour. When in the air, flying fish hold their breath, just like when we swim in water. As their bodies begin to descend near the surface of the water, flying fish will move their tails to return to a higher position so they can stay afloat. Their tails can also be used to change course/direction. With this technique, flying fish can stay above the surface of the water for up to 43 seconds and can cover a distance of up to 400 m. Flying fish that have four wings can glide up to 400 m, and perform turns and changes in altitude. Whereas those with two wings travel shorter distances, usually in a straight line (Davenport 1994).

The reproductive process of flying fish is oviparous, in which it breeds by laying around 7000 eggs (Khokiattiwong *et al*. 2000), even reaching 16,000 to 24,000 eggs in certain species that have a larger shape. Fecundity or the number of eggs varies in each species and can be affected by the latitude and location of fish life (Mann *et al*. 1984). Some flying fish have special egg structures that allow the eggs to attach to floating objects or seaweed, while others lay their eggs on the surface of the open sea (Collette *et al*. 1984). After spawning, flying fish usually continue in coastal habitats to complete their life cycle, while others continue their life cycle offshore.

The study of flying fish population structure was carried out based on analysis of fish DNA from species collected from the Pacific Ocean, Atlantic Ocean and Indian Ocean as many as 266 samples. Gene pedigree analysis, analysis of molecular variance, clustering analysis, and history of population growth explain the high level of gene flow, population expansion and the wide geographical distribution of flying fish species (Lewallen *et al*. 2018). In addition, Chou *et al*. 2015 have also studied the population structure of flying fish based on the mtDNA cytochrome oxidase I (COI) gene to provide useful information for sustainable resource management.

Flying Fish Distribution

Flying fish live in tropical and subtropical waters. The number of flying fish species in the equator is greater, the further north or south the number of species is less. These fish are an important component of the food chain, as well as an important fish resource in Indonesian waters (Zerner 1986), Taiwan (Chang *et al*. 2012b), the eastern Mediterranean Sea (Ali 2018), Atlantic (Wirtz *et al*. 2017), India, Pacific Islands (Gillet and Ianelli 1991), Eastern Caribbean (Mahon *et al*. 1986), Netherland, West Africa, China and the Sea of Japan (Parin 1960; FishBase 2022) as well as in the Philippines, Vietnam and Thailand. There are about 52 species of flying fish in the world, 17 species each in the Atlantic Ocean, 11 species in the Indian Ocean and up to 50 species in the Pacific Ocean (Chang *et al*. 2012a; Xu *et al*. 2013).

In Indonesia, the spread of flying fish starts from the west to the east of its waters. Some of these water areas include the Makassar Strait, Flores Sea, Banda Sea,

Sulawesi Sea, Maluku Sea, Sawu Sea, Tomini Bay to the Java Sea (Yahya 2006). Based on the flying fish distribution map in Indonesia, it can be seen that the distribution of fish species from west to east is dominated by *Cheilopogon, Cypselurus, Exocoetus, Hirundichthys, Parexoccetus, Prognichthys* (berwarna kuning) dan *Cheilopogon, Cypselurus, Exocoetus, Parexoccetus, Prognichthys* (berwarna hijau), can be seen in Figure 1. The spatial distribution of flyingfish can be influenced by oceanographic factors that affect spawning and growth processes. Several oceanographic parameters that can affect the distribution of fishes are SST (Sea Surface Temperature), chlorophyll–a, salinity, and others. Each type of fish has different optimal level of particular oceanographic parameters. Beside that, the distribution of oceanographic parameters are effected by West monsoon, East monsoon and the season inbetween.

Chlorophyll-a concentration, sea surface temperature, waves, depth and current speed affect the presence of flying fish. Flying fish are found in the chlorophyll-a range of 0.25 – 0.70 mg/m^3, sea surface temperatures of 27.5-29.5°C, current speeds of 25.0 – 42.5 m/s (Zainuddin 2011) and waves between 0.70 – 1.60 m (Boli *et al*. 2019). A survey conducted by Churnside *et al*. 2017 found schools of flying fish at an average depth of 5.27 m at night and 4.61 m during the day. The mismatch of oceanographic parameters in the waters can limit the distribution of flying fish species thereby affecting population size.

Flying fish lay eggs and attach their eggs to floating objects (Casazza *et al*. 2005). Even though these fish can swim in deeper seas, they still attach their eggs to floating objects. This is thought to be due to the positive effect of warmer temperatures on the surface of the waters in the egg development phase (Uygun and Hossucu 2018) and protecting the eggs during the critical early life phase (Stevens *et al*. 2003).

Production And Fishing Gear

Initially, flying fish caught using simple and small-scale equipment, then developed using gillnet fishing gear (Najamuddin *et al*. 2020; Emperua *et al*. 2017; Palo *et al*. 2019; Chang *et al*. 2012a). Gill nets are the dominant fishing gear used by fishermen, especially for catching small pelagic fish (Rema *et al*. 2022). There is not enough historical evidence to pinpoint a specific time period when flying fish fishing began, but gillnets are known to have been used to catch flyingfish. The flying fishing season is March-July (Huang and Ou 2012) and flying fish roe season is May-September (Suwarso *et al*. 2008).

The production of flyingfish can provide an overview of the condition of flyingfish in Indonesia in general. Flyingfish production in Indonesia from 2010-2018 (x axis) showed that the largest catch was in 2016 amounting to 25,237 tons (y axis), as shown in Figure 2 (KKP 2023).

Eggs produced by flying fish are an important commodity in several waters. Flying fish eggs can generate quite high foreign exchange as one of the fishery export commodities to various countries, such as Japan, Europe and America. In Indonesia, the price of flying fish eggs is in the range of IDR 120,000/kg (Yahya 2006). The flying fish species (*Hirundichthys affinis*) is reported to be the largest supporter of single species fisheries in the eastern Caribbean (Khokiattiwong *et al*. 2000).

The abundance of flying fish is influenced by oceanographic conditions in the form of sea surface temperature, chlorophyll, currents and waves (Boli *et al*. 2019; Zainuddin 2011). In addition, the abundance and distribution of flying fish is also strongly influenced by the presence of upwelling in the waters. The flying fish fishery forms a seasonal pattern which usually lasts less than seven months each year (Jayawardana and Dayaratne 1998). Studies on the distribution of fishing grounds and their suitability as bait fish for large pelagics have been carried out. There are seasonal fluctuations in the flying fishery which are believed to be influenced by oceanographic factors (Jinadasa, 1985; Jayawardana and Dayaratne 1998). Schooling of pelagic fish is known to be influenced by light intensity associated with the phases of the moon (Karunasinghe and Wijeyaratne 1996; Freon and Misund 1999). Related to this, it is suspected that the efficiency of flying fishing is influenced by the annual month pattern (Croos 2009).

Utilization Of Current Technology in Flyingfish Research

The population structure of each type of fish is one of the important things, considering the importance of preserving fish resources in the waters. Understanding the structure of fish populations is very important for documentation of genetic, species and evolutionary diversity as well as fisheries management efforts for a particular fish species. Especially for fish species such as flying fish which have important economic value and include fish that

do not live long. Flying fish can be categorized as crucial pelagic fish that live in tropical and subtropical areas. This is because flying fish are consumption fish and have eggs which are one of the export commodities (Indrayani *et al*. 2020).

Churnside *et al*. 2017 conducted a survey on the distribution and abundance of flying fish using airborne lidar combined with direct observations using survey vessels to obtain species and size data. Direct observation can be used for remote data validation and calibration. The survey found that the average fish population is 10,000 and is near the surface of the waters. Schools of flying fish are in deeper water at night than during the day. The use of remote sensing data has also been used by Zainuddin 2011 to obtain the distribution and abundance of fish in relation to oceanographic conditions in the form of sea surface temperature, chlorophyll and current speed. This research uses remote sensing technology in the form of Multi-Spectrum Satellite Images. Flying fish is a type of pelagic fish that has a wide distribution in waters, making it possible to use remote sensing data to obtain data with a wider coverage.

Flying fish studies using acoustic technology have been carried out. Brehmer *et al*. 2007 reported that schools of flying fish were detected using sonar. According to him, this research is the first study that can detect schools of flying fish in waters using sonar. The school was also verified by visual observation at close range to confirm that the school was flying fish. Apart from the use of sonar, tagging technology has also been used to show the movement patterns and distribution of flying fish (Mulloney 1961; Lewis 1964; Oxenford 1994). However, tagging technology is difficult to apply on a large scale and may also be difficult to apply to flying fish due to the size of the fish. An understanding of the behavior, distribution, abundance, population and environmental conditions of fish needs to be known as an effort to manage its resources.

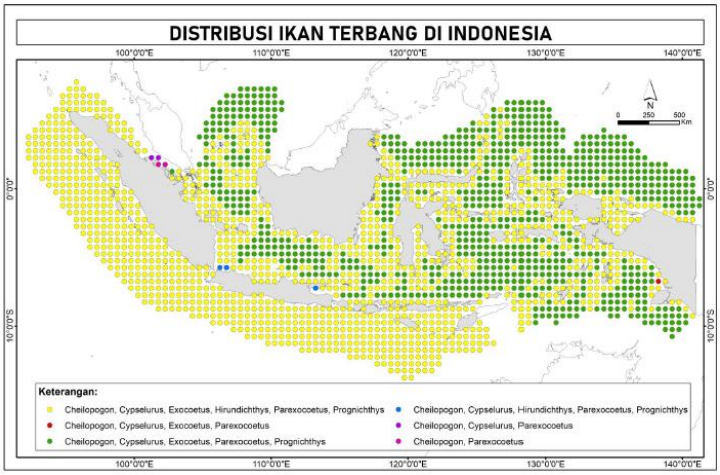

Figure 1 The distribution of flyingfish habitats is based on the probability of finding the species (Fishbase 2022)

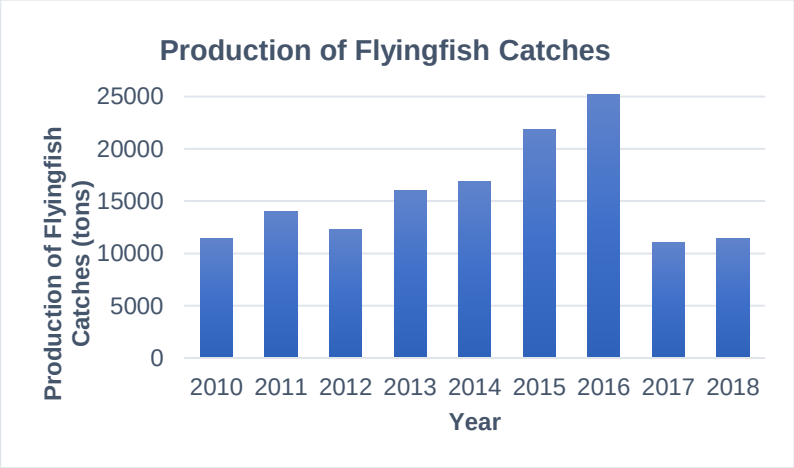

Figure 2 Production of Flyingfish Catches in Indonesia in 2010-2018

CONCLUSION

Flying fish are economically important fish in various countries and are one of the aquatic resources that deserve attention for the sustainability of their resources. The literature study was carried out as a first step in flying fish research which has not been widely published. The literature study shows the classification, types, spawning process, body shape, ability to glide in the waters, distribution, fishing technology, and the latest technology in various research.

RECOMMENDATIONS

The results of this study are expected to contribute to managing flying fish resources. Even though fish resources are resources that can recover, if they are not managed properly and appropriately, the rate of recovery may not match the speed of exploitation. For this reason, it is necessary to conduct a thorough study to find out the appropriate policies for managing flying fish resources.

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