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Squid Harvest Strategy Review for the East China Sea and Yellow Sea Japanese flying squid FIP

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Introduction

Globally, there is no universal management strategy established for squid fisheries. Most squid species have an extremely short life history, biological characteristics associated with high productivity, and recruitment that is strongly influenced by environmental factors (Agnew et al. 2002). Stock-recruit relationships are weak or not well understood, meaning that the number of recruits is not necessarily proportional to the spawning biomass. These characteristics result in highly variable population dynamics and make standard finfish stock assessment models less appropriate for assessing squid (Pierce and Guerra 1994). A traditional, sequential approach of stock assessment, total allowable catch (TAC) establishment and catch monitoring/harvest controls against TAC targets has very limited functionality in terms of achieving maximum sustained yield management objectives.

Japanese flying squid (*Todarodes pacificus*, hereafter abbreviated as JFS) in China can be characterized as having largely a one-year life cycle where adults die after spawning. They undergo regular spawning migrations and are caught by Chinese, Japanese, and South Korean fishing fleets. In the current China management system, no stock assessment or active harvest strategies that include harvest control rules with abundance threshold triggers exist for squid. Chinese regulatory tools to restrict squid harvests are primarily input controls, specifically limits on the numbers and engine power of vessels, though they have not been actively employed to address what is widely considered to be overcapacity in the domestic Chinese commercial trawl fleets. The summer moratorium that bans most commercial fishing activity in the Bohai, Yellow, and East China seas from 1 May to 1 September each year is the primary regulatory measure that affects squid exploitation.

An essential element of the East China Sea and Yellow Sea Japanese flying squid fishery improvement project (FIP) is the review and recommended considerations of harvest strategies to Chinese government representatives through developing an engagement process that will meet sustainability requirements as well as practically fit the likely capacities of a developing Chinese fisheries management system.

From a market availability standpoint, the management approach should fit a highly variable recruitment and abundance pattern due to fluctuating environmental conditions. An optimal approach would provide adequate protection at low stock sizes and take full advantage of harvest opportunities when abundance is high.

Objective

This analysis is intended to draw on various squid management experiences globally and evaluate their potential applicability to the JFS case. While enabling conditions are not likely to lead to an immediate adoption, understanding the best harvest management strategy fit(s) will help frame an iterative discussion with Chinese managers and scientists and also have an important benefit of helping refine catch and biological monitoring approaches and stock assessment design considerations.

Review of squid harvest management: 3 case studies

Commercial squid fisheries usually target aggregations of larger individuals, which may be spawning aggregations (consisting of mature individuals) or migration aggregations (consisting of pre-mature individuals). Fisheries targeting migration aggregations need to be especially precautionary with regards to the harvest strategy, since they mostly catch squid that have not yet had a chance to spawn. In either type of fishery, management should aim to minimize the possibility of recruitment overfishing, which occurs when the mature adult population (spawning biomass) is depleted to a level where there are not enough adults to produce offspring and replenish the population. However, estimating abundances is notoriously challenging for squid, since recruitment is strongly influenced by environmental conditions. For example, factors such as water temperature and prey availability affect hatching success and paralarval survival and growth (Vidal et al. 2006; Pierce et al. 2008). Dependence between spawning stock size and recruitment of squids generally is not generally well-established, and population abundances are highly variable (Rodhouse et al. 2014).

There is no single harvest strategy considered to be standard practice for squid. According to international best practices and Marine Stewardship Council (MSC) guidance, a robust harvest strategy aims to control fishing mortality to biologically sustainable levels through a combination of monitoring (particularly in relation to stock abundance and exploitation rates), stock assessment, harvest control rules (HCRs) and management actions required for maintaining fishery sustainability. Because squid have short lifespans, fisheries essentially exploit one population cohort within a season (Agnew et al. 2005), and as mentioned above, abundance is associated largely with environmental conditions (e.g. Sakurai et al. 2000). Thus under intensive exploitation regimes, harvest management should involve frequent monitoring and evaluation of the stock, at least once per year. Longer term changes in climate are also important to consider (Pierce et al. 2008).

Below we describe some case studies that may be useful for developing a harvest strategy for China's JFS fisheries, specifically Falkland Islands, California (US), and US East Coast squid fisheries. We additionally note that Japan has commercial fisheries for JFS, which are managed using stock assessments and setting of TAC. The assessments use catch per unit effort (CPUE) as the abundance indicator (Kaga et al. 2019). Scientists estimate allowable biological catches (ABCs) for each of the two JFS stocks and use that information to set a single TAC for both stocks combined, which is further allocated among gear types.[1] For this review, however, we will focus on other management cases, particularly those in which fishery closures are triggered in response to in-season monitoring.

[1] http://www.jfa.maff.go.jp/j/suisin/s_tac/attach/pdf/index-98.pdf

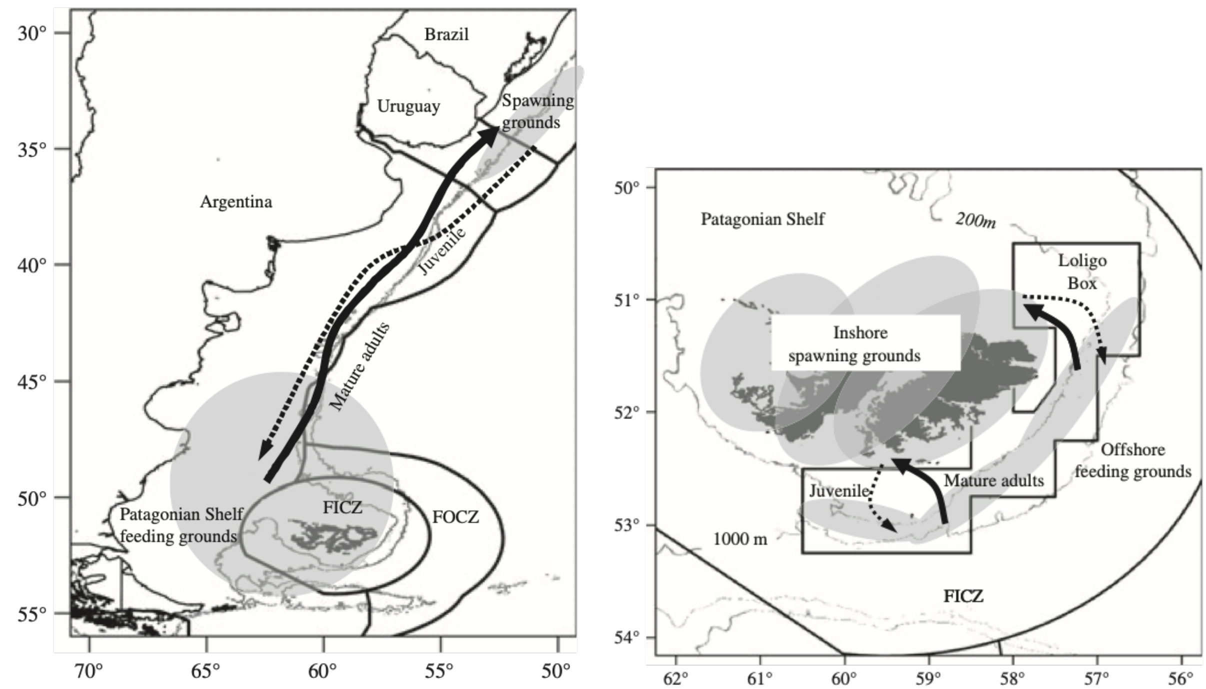
Case study 1: Falkland Islands

The Falkland Islands, a British overseas territory, has one of the most intensively managed squid fisheries in the world. The two commercially targeted species are Argentine shortfin squid (*Ilex argentinus*; hereafter referred to as shortfin squid) and Patagonian squid (*Doryteuthis (Loligo) gahi* and referred to in this case study as loligo). There are several spawning groups of shortfin squid, including a winter-spawning component that is dominant (~95%) in terms of total species abundance (Arkhipkin et al. 2013). The winter-spawning component consists of two stocks: the Bonaerensis North Patagonian stock and the South Patagonian stock. Shortfin squid migrate into the Falkland Islands Coastal Zone starting from late January, and migrate out of the zone in May and June.

Loligo squid are managed as a single stock that recruits to the fishery as two cohorts, one in the summer, and one in the autumn-winter (Agnew et al. 2000). This species undergoes ontogenetic migrations, where juveniles move from inshore spawning grounds to feeding grounds near edge of the Patagonian shelf (Arkhipkin et al. 2000). After feeding and growing in these offshore feeding grounds, loligo squid mature and migrate back to inshore waters to spawn.

Commercial fishing takes place in two fishing zones around the islands, called the Falklands Interim Conservation and Management Zone (FICZ) and the Falkland Islands Outer Conservation Zone (FOCZ; Fig. 1a). In both zones combined, total annual catches of fishes and squid averaged 280,000 tonnes from 1989 to 2000 (Arkhipkin et al. 2013). Shortfin squid are harvested from March to May, largely by jiggers from Taiwan, South Korea and Japan (Falkland Island Fisheries Department 2019). Shortfin squid straddle multiple exclusive economic zones (EEZs; Fig. 1a). The loligo squid harvested by the Falkland Islands fishery occurs entirely within the FICZ, so this can be considered a domestic fishery.

Loligo squid are caught by bottom trawl prior to their spawning migration (McAllister 2004). There is an area in Falkland waters colloquially called the 'Loligo box' throughout which commercial trawlers can harvest loligo squid, except within the 3-mile coastal zone of the islands (Fig. 1b).



Figures 1a (left) and 1b (right). (1a) Migration routes for *Illex argentinus* off the South American coast, and the two fishing zones around the Falkland Islands (FICZ and FOCZ). Solid black lines denote country EEZs. (1b) Migration routes for *Doryteuthis gahi* and the 'Loligo box' fishing zone. Figures from Arkhipkin et al. (2013).

Access to the commercial fishery is limited through a licensing system. There are currently nine licensed fisheries in the Falkland Islands, categorized by multispecies or single species groups (Arkhipkin et al. 2013). In eight of these fisheries, including the loligo squid fishery, an individual transferable quota (ITQ) system is in place. These ITQs are allocated for 23 to 25 years. The ninth fishery, the one for shortfin squid, issues short-term, seasonal licenses. As of 2013, seven companies held ITQs for loligo squid, with 16 factory trawlers licensed to catch this species (Arkhipkin et al. 2013). The fishery for shortfin squid is mostly undertaken by squid jigging vessels from other countries including South Korea and Taiwan. Numbers of licensed jigging vessels varied from 42 in 2008 to 100 in 2012 (Arkhipkin et al. 2013). As part of their license agreement, fishers have to report their catch, duration of trawling, mean fishing depth and position on a daily basis (Arkhipkin et al. 2000). The Falkland Islands Fisheries Department operates an observer program where observers are placed on commercial fishing vessels for three to six weeks. While onboard, the observers randomly subsample catches, measuring mantle lengths (ML) and assigning sex and maturity stage for individual squid (Arkhipkin et al. 2000). They also monitor seabird interactions and regulatory compliance of the fishing vessels (Arkhipkin et al. 2013).

The Falkland Islands loligo squid fishery has a complete harvest strategy that includes in-season stock assessment, monitoring, and controls on fishing effort, as described by Arkhipkin et al. (2013). There are two discrete commercial fishing seasons per year, each targeting a different squid cohort. Prior to each fishing season, scientists work with commercial trawlers to conduct a recruitment biomass survey lasting about two weeks. Survey data are used to estimate total biomass across the fishing zone, which is used as an indicator of expected harvest outcomes. Once the fishing season begins, trawlers transmit daily reports of catches by species, fishing effort in trawl hours, and noon position to the Falkland Islands Fisheries Department (FIFD). The vessels also keep an electronic logbook of catches and geographic positions for each trawl, and market-size categories (based on ML) of the harvested squid. The electronic logbooks transmit daily to the FIFD. Fishery observers will join one or two vessels at a time during the season to collect additional data on size distributions.

Scientists use these data in a depletion time-series model to estimate stock size throughout the fishing season and assess status against biological reference points set in terms of minimum spawning stock biomass. The model also projects biomass at the end of the season, and scientists monitor the projections to maintain a conservation threshold of 10,000 tonnes (minimum spawning biomass)[2] of loligo squid at the end of the season. If the threshold appears likely to not be met, the fishery may be closed early, where companies are given seven to ten days notice to stop fishing (Agnew et al. 2002, Arkhipkin et al. 2013). The season is always scheduled to close before the squid in the targeted cohort are ready to spawn (Arkhipkin et al., 2013). Loligo squid undergo a more comprehensive re-assessment at the end of the season.

As noted above shortfin squid migrate and are fished across multiple EEZs, and past management involved international cooperation. For example, Argentina and the Falkland Islands share the South Patagonian stock of shortfin. In 1990, the United Kingdom and Argentina created a regional fisheries management organization (RFMO) called the South Atlantic Fisheries Commission (SAFC). Under the SAFC the two countries shared fisheries data and collaborated to conduct stock assessments and make management recommendations. In 1993, Argentina and the Falkland Islands agreed to implement a system wherein fisheries in both EEZs would be closed early if assessed biomass fell below a conservation reference point (Arkhipkin et al. 2013). However, Argentina decided not to continue with the cooperative process and suspended joint scientific activities in 2005 (Mercopress 2012). Currently management measures are imposed separately by each country.

The Falkland Islands harvest strategy for shortfin squid is similar to that for loligo. Scientists conduct a recruitment survey prior to the fishing season, which starts in February (Arkhipkin et al. 2013). Vessels submit daily catch reports, which include information on the number of working fishing lines (for jigging vessels) and number of working hours in addition to catch data. Stock abundance is estimated using a DeLury depletion model that considers in-season migration of squid into the fishing grounds (Basson et al. 1996). If assessed biomass falls below a conservation threshold of 40,000 tonnes, initially established via bilateral agreement in 1993, the fishery may be closed early. Although the basis for the threshold is unclear, it apparently was established in recognition that a previously defined proportional spawning escapement target for the fishery of 40%, regardless of biomass levels, would be insufficient to conserve the

[2] Established under bilateral agreement in 1993 (Agnew et al. 2005).

stock at low population sizes, where there likely would be a direct relationship between biomass and future recruitment (Agnew et al. 2005).

Catches of both species have been sustained over the past few decades, although more severe fluctuations have been observed for shortfin squid since 2001 (Fig. 2). It should be noted that catch and CPUE (catch per unit effort) do not reflect total abundance of shortfin squid in the southwest Atlantic Ocean, because the squid do not migrate as far south as Falkland waters during cold years (Falkland Islands Government, 2012). Nevertheless, the reduction in multi-national, cooperative management for shortfin squid may be increasing the vulnerability of the stocks to overexploitation (Arkhipkin et al. 2013).

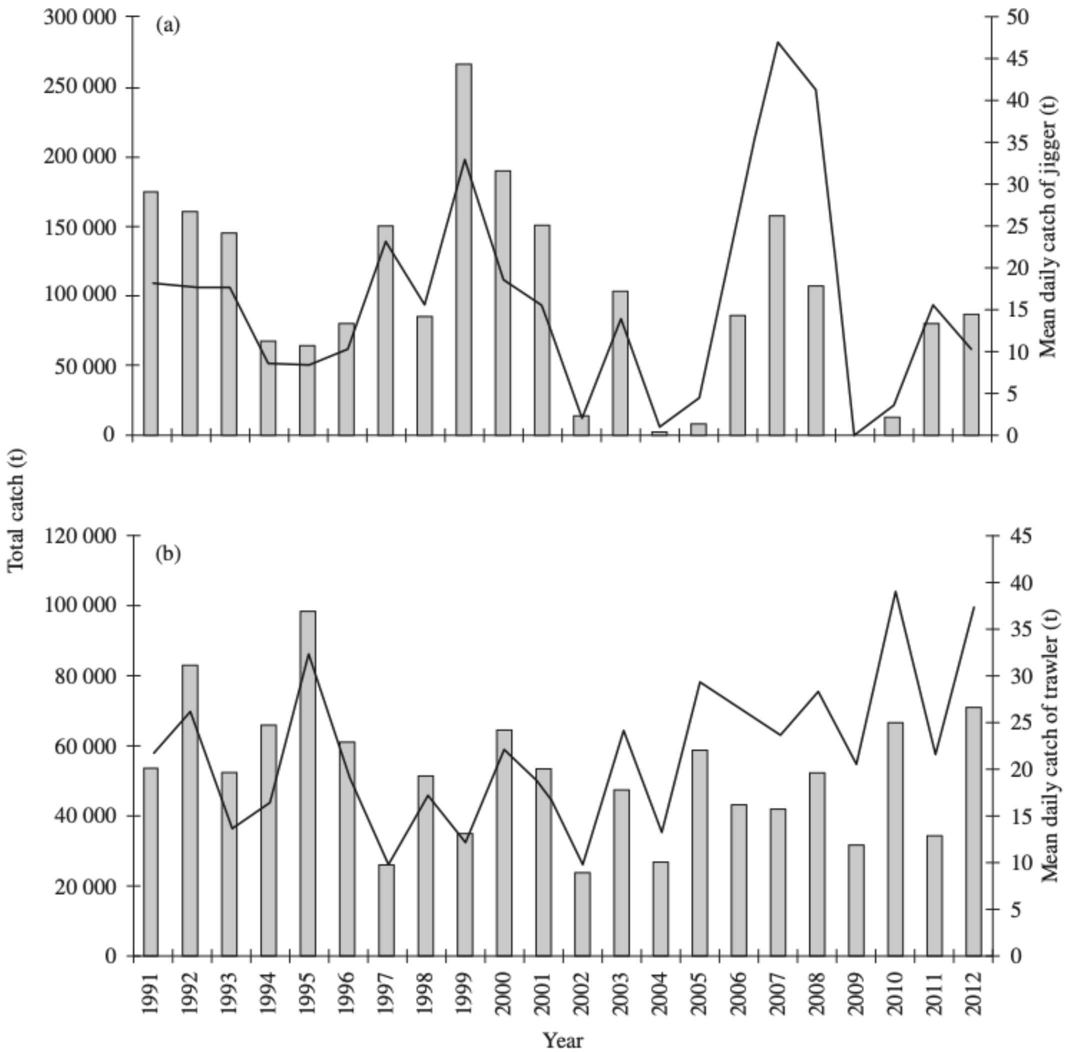


Figure 2. Annual total catches (grey bars) and mean daily catch per unit effort (CPUE; solid black line) for shortfin squid (*I. argentinus;* a) and loligo (*D. gahi*; b). Figure from Arkhipkin et al. (2013).

From a scientific standpoint, the Falkland Islands' harvest strategy for squid is quite rigorous, since it involves real-time management and is highly responsive to the status of the stocks. Efforts are made to allow the squid to spawn before harvesting them, which reflects a precautionary approach. However, this type of management is very time and resource intensive, and may be most applicable to fisheries with smaller, manageable fleets since close communication and coordination are needed (MAFMC 2013b).

Case Study 2: US Northwest Atlantic

Two species of squids are commercially harvested in the Northwest Atlantic region off the eastern coasts of Canada and the United States of America (US): Northern shortfin squid (*Ilex illecebrosus*) and longfin inshore squid (*Doryteuthis (Loligo) pealeii*; hereafter referred to as longfin squid). Both species have been exploited since the late 1800s, but fishing pressure increased rapidly as the species gained commercial importance, peaking in the 1970s when large industrial trawlers from Japan, the former USSR, and Western Europe targeted both species for food (Arkhipkin et al. 2015). The squid fishery subsequently became solely domestic in 1987, after the foreign fleets were no longer authorized to fish within the US EEZ (exclusive economic zone; DeAlteris et al. 2018). The US Northwest Atlantic fishery for longfin squid is currently the only MSC certified squid fishery and is our focus for this case study.

Longfin squid are semelparous and live less than one year. They occur in the Atlantic Ocean from Nova Scotia to the Gulf of Mexico, and are managed by the US as a single stock off the US East Coast (NEFSC 2011). The squid are comprised of two seasonal cohorts, which generally go offshore during October-March and then move inshore and south from April to September (Hendrickson 2017). Fishers follow these seasonal migration patterns such that there is an offshore winter fishery and inshore summer fishery. Small mesh bottom trawls are the predominant gear used to catch longfin squid. Commercial fishers must obtain a permit to access the fishery, and about 190 vessels of varying sizes actively fished for longfin squid in 2016 (DeAlteris et al. 2018). Recruitment occurs throughout the year and is largely driven by environmental factors such as temperature (Jacobson 2005). Due to ongoing recruitment there are seasonal cohorts, each with an average lifespan of six months. Squid caught in the offshore winter fishery (October to March) mostly hatched about six months prior during the summer, while squid caught in the inshore summer fishery hatched 6 months prior during the winter.

The stock is currently assessed based on a catchability-adjusted swept-area biomass method (Hendrickson 2017). Biomass indices are estimated using daytime tows conducted by the Northeast Fisheries Science Center (NEFSC) in spring (March-April) and fall (September-October), and Northeast Area Monitoring and Assessment Program (NEAMAP) fall (September) bottom trawl surveys. Only daytime catches are used to estimate biomass because the capture efficiency of bottom trawls is highest for longfin squid during the day (Brodziak and Hendrickson 1999). Discards and landings data were used to update catch estimates for 2010 to 2016 (Hendrickson 2017). The spring and fall biomass estimates are used to represent the seasonal cohorts available to the January-June and July-December fisheries, respectively. In 2017, stock status was determined based on the 2015-2016 average of the spring and fall biomass.

Seasonal and annual relative exploitation indices are computed as catch divided by survey biomass (Hendrickson 2017).

There are no fishing mortality reference points for the stock, because there appears to have been no clear statistical relationship between squid catches and annual biomass estimates from 1975 to 2009 (MAFMC 2013a). However, there are biomass reference points. The biomass target associated with MSY (B_{MSY}) was established in 2010 based on a base period (1976-2008) average of biomass estimates when longfin exploitation was very light, where this average biomass was considered to represent 90% of carrying capacity. The proxy B_{MSY} was then set at 50% of carrying capacity, or 42,400 mt, and the limit reference point was set at 50% of B_{MSY}, or 21,200 mt (Hendrickson 2017).

The longfin squid stock assessment noted that management using either a fixed TAC or fixed effort is likely to result in lost yield when the squid population is highly productive, and may not adequately protect the resource when productivity is low, due to highly variable recruitment (Hendrickson 2017). In-season assessment and management, combined with allowance of adequate spawner escapement from each seasonal fishery are needed to maintain the resource and harvest it at optimum yield. However, there are currently insufficient resources to implement in-season management at an optimal time scale (MAFMC 2013a).

The Mid-Atlantic Fishery Management Council (MAFMC) manages the squid fishery using harvest control rules based on acceptable biological catch (ABC). Recommended harvest specifications are developed by the Atlantic Mackerel, Squid, and Butterfish Committee of the MAFHC; the Science and Statistical Committee (SSC); and the MAFMC Atlantic Mackerel, Squid, and Butterfish Monitoring Committee (Monitoring Committee). These committees work together to develop ABC recommendations and assign specific control rule levels for the squid stocks. First they set a maximum optimum yield (OY). The longfin squid ABC is set at either the maximum optimum yield (OY) or a lower level, if stock assessments indicate that potential yield is less than OY. For species that lack fishing mortality reference points, such as longfin squid, the SSC recommends an annual ABC equal to the catch in the year of the highest exploitation ratio, defined as catch divided by biomass. For longfin squid this is 23,400 tonnes, the catch in 1993. The ABC may be adjusted based on economic factors.

The MAFMC uses in-season harvest quotas so that catches do not exceed the ABC. Quotas were set quarterly from 2001-2006, and then three times a year (trimester quotas) from 2007-2017. The fishery is closed when quotas are attained, based on in-season monitoring. The fishery may also be closed if vessels attain quotas set for bycatch species such as butterfish. These in-season fishery closures have occurred every year since 2000, except in 2010, 2013 and 2015 (Hendrickson 2016). In terms of input controls, there are requirements on minimum mesh sizes (MAFMC 1995).

Overall, harvest management for US North Atlantic longfin squid may be considered an intermediate case in terms of capacity requirements. The setting of trimester quotas allows for some responsiveness on an intra-annual timescale without being as intensive as real-time monitoring.

US California squid fisheries

Market squid (Doryteuthis opalescens)

Market squid are a short-lived, semelparous species with a distribution from Mexico to Canada off the Pacific coast of North America (Anderson 2000). They have a lifespan of about six months and mostly recruit to the fishery in spring-summer in northern California and autumn-winter in southern California (Butler et al. 1999, Reiss et al. 2004). The fishery is co-managed by the Pacific Fishery Management Council (PFMC) and the California Department of Fish and Game (CDFG).

Since the 1990s, harvests have been managed via harvest control rules that include an annual catch limit and specific spatial and temporal fishing constraints. In 2005, CDFG adopted a fishery management plan (FMP) that set the annual catch limit at 107,048 tonnes (118,000 short tons), maintained weekend closures (noon Friday to noon Sunday), included restrictions on usage of attraction lights, and limited access to the fishery through a permitting program (CDFG 2005). Compared to the previous case studies, the stock reference points used in the California market squid harvest strategy do not appear as robust. The catch limit is not based on a biological model; rather, it is based on the 3-year average catch from the 1999-2000 to 2001-2002 fishing seasons, when abundance did not appear to be declining (CDFG 2005). Setting limits using historical catch data from such periods of non-declining abundance may be justifiable in data-poor situations (Restrepo et al. 1998). There is no limit reference point, such as a minimum biomass below which fishing should not occur. The catch limit has been exceeded twice since 2005, in 2010 and 2011, suggesting that enforcement is only moderately effective (MBA Seafood Watch 2019).

Stock assessments are not regularly conducted for market squid. Scientists have determined that standardized catch-effort data are not reliable proxies for market squid population abundance, because fishery exploitation rates are strongly influenced by market demand, processing capacity and availability (Dorval et al. 2013). When demand is low, fishers usually stop targeting market squid and instead shift their efforts towards other coastal pelagic species. When landings approach processing capacity, the price drops, and fishers stop fishing for squid, even though abundance and/or availability to the fishery are not limiting factors. In recent years, some of the other species that these fishers target have been closed to fishing, which has increased fishers' reliance on squid (C. Akselrud, pers. comm.,17 October 2019).

Fishery mortality reference points do exist, using egg escapement as a proxy for fishery exploitation rate that on average will achieve MSY, i.e. F_{MSY}. Scientists developed an eggs per recruit model to evaluate population dynamics and set an egg escapement for in-season management (Dorval et al. 2013). In this type of model, fishing mortality (F) is directly inferred from fecundity of harvested females, allowing for development of proxies for biological reference points based on F. The model is based on a daily time step because mature squid may live for only a few days before being caught by the fishery. As part of the data collection process to estimate parameters for the model, landings were sampled monthly from two randomly selected vessels at each of three ports. At each sampling event, scientists randomly sampled 30 individual squid per vessel, measured mantle length (mm) and body weight (g), and determined their sexes (Kong et al. 2003). Six of these thirty squid (one male and five females) were randomly selected for maturity assessment and estimation of catch fecundity, defined as the number of oocytes and ova in the ovaries and oviducts of harvested females.

The authors noted that the model would likely be too costly and time-consuming to apply for real-time, in-season management. However with further development, the model could be used to help set a varying escapement threshold in an adaptive manner. The model also provided an analytical approach for estimating absolute abundance of the spawning population using relatively limited information, i.e. catch and biological time series, and fishing mortality estimates.

A review of the market squid F_{MSY} proxy, which represents a 30% spawning escapement rate from the fishery, can be compared to the 40% escapement rate for the Falkland Islands shortfin case study noted above (PMFC 2002). A key difference between the two fisheries is that the Falkland shortfin fishery largely targets juvenile squid while the California fishery largely targets mature spawning aggregations, doesn't operate on all spawning grounds, and uses weekend closures to assist spawning escapement. These factors were cited as reasons for a greater fishery exploitation rate associated with MSY than in the Falkland case.

Of these three case studies, the California market squid is perhaps the most similar to the China JFS fishery in terms of being somewhat limited in terms of stock assessment information.

Considerations for China's JFS Fishery Management

Description of the China JFS FIP fishery

The East China Sea and Yellow Sea Japanese flying squid FIP fishery is defined as follows.

Target species: Japanese flying squid (*Todarodes pacificus*), also known as Japanese common squid, スルメイカ (Japanese), and 太平洋褶柔鱼 (Chinese). This species is called "dark-skin squid" in Zhoushan area, Zhejiang Province.

Geographical Area: offshore areas in China's EEZ including portions of the East China Sea and Yellow Sea

Method of Capture: Midwater and bottom trawls (operated by single or paired vessels). Our understanding is that trawlers do not use lights to attract target species, but Chinese purse seiners using lights may operate in the Sea of Japan.

Stock: Fall and winter spawning stocks of Japanese flying squid. A summer spawning stock exists as well but is thought to be relatively small and insufficient for supporting large-scale fisheries. The winter-spawning stock is dominant in the East China Sea and Yellow Sea.

Relevant management bodies:

- Fisheries Bureau under the Ministry of Agriculture (national level)
- State Oceanic Administration, which oversees enforcement agencies (national level)
- Zhoushan Dinghai Ocean and Fishery Bureau (local level)

Japanese flying squid (*Todarodes pacificus*) have a broad geographic distribution within the Northern and Western Pacific Ocean. They are native to waters off Japan, mainland China, Taiwan, South Korea, North Korea, and Russia, and are found in both the open ocean and coastal regions (Roper et al. 2010). Near China, JFS can be found in the South China Sea, East China Sea, and Yellow Sea, but generally not the Bohai Sea (Kiyofuji and Saitoh 2004).

JFS populations are highly migratory, moving to forage and reproduce (Fig. 4). Three sub-populations, also called stocks or spawning cohorts, have been defined based on their spawning seasons: winter, fall, and summer. There are occasional references to a spring spawning stock, but documentation is minimal, and this stock is probably small. Genetic analyses are limited but suggest the existence of two distinct breeding groups: 1) the fall stock and 2) the winter, summer and spring stocks combined (Kang et al. 1996, Katugin 2002). The fall and winter stocks support large-scale fisheries, while the summer spawning stock supports only small-scale fisheries. Fishery catches in fall and winter are dominated by mature squid, whereas spring and summer catches are dominated by juvenile squid (Yang et al. 2010). Recent harvests have mostly taken place in the fall and winter due to the summer fishing moratorium, so catches are expected to be predominantly mature squid.

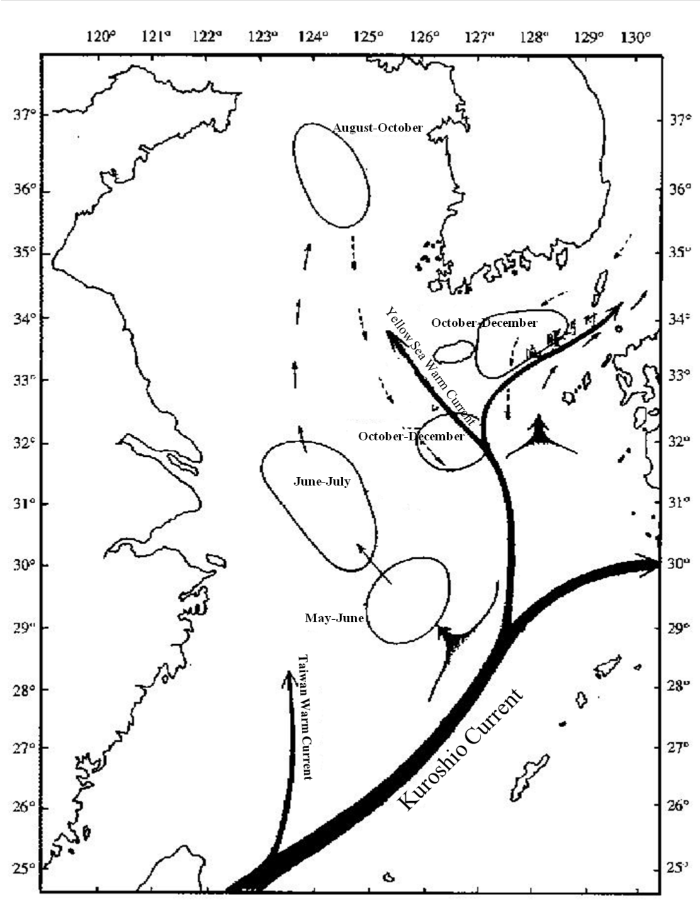


Figure 4. Migration route of JFS for the winter stock, shown with the arrows. From Song et al. (1999).

Outside of the East China Sea China EEZ, offshore trawlers harvest JFS in the East China Sea Yellow Sea, and Sea of Japan, in areas co-managed with Japan and South Korea through bilateral agreements and also through sanctioned business to business arrangements between Chinese and North Korean entities. Although not a part of the FIP, JFS are also commonly caught using stow nets close to shore (Table 1).

Table 1. Numbers of vessels (No.) registered to Zhoushan ports and their total power (in megawatts; MW), separated by gear type. Source: Fishery Statistics Yearbook of Zhejiang Province by Zhejiang Ocean and Fishery Bureau.

年份 Year	拖网船 Trawler		围网船 Purse Seine		刺网船 Gill Net		张网船 Stow Net		钓业 Line		其他 Others		远洋渔船 Overseas	
	艘 No.	千瓦 MW	艘 No.	千瓦 MW	艘 No.	千瓦 MW	艘 No.	千瓦 MW	艘 No.	千瓦 MW	艘 No.	千瓦 MW	艘 No.	千瓦 MW
2010	2345	485	267	66	956	108	2475	317	685	136	740	69	251	134
2011	2125	448	290	73	1134	115	2536	345	689	166	782	66	335	206
2012	2110	452	336	85	1235	76	2543	354	676	226	673	51	383	247
2013	2123	473	327	81	1107	114	2362	330	763	250	740	55	406	284
2014	1954	412	342	87	1215	127	2204	319	522	279	599	69	419	302

Data monitoring

One major consideration for harvest strategy development is the level of monitoring and data availability. China's fishery management system does not regularly conduct species-specific monitoring. Fisheries production, trade, and species statistics are collected and compiled by the central fisheries statistical division, which regularly reports them to the United Nations Food and Agricultural Organization (FAO). Fisheries information and statistics are disseminated through national statistical bulletins, Chinese Fisheries Yearbooks, Chinese Fisheries Statistical Yearbooks, and government websites (He 2015). However, the FAO has noted a lack of effective monitoring and oversight of fisheries data in China (FAO 2008).

The MSC pre-assessment conducted by Ocean Outcomes (2016) provides an overview of the data available for JFS stocks in China. Available information on catches is largely limited to the China Fisheries Yearbook, which presents only highly aggregated data and does not have catch data separated by species, gear, or area. Catches are separated by province but refer to catches by the vessels based in each province, which may include catches from outside the province or even outside of China's EEZ. At a Packard Foundation-funded workshop held 14-18 October, 2019, scientists from China's Yellow Sea Research Institute (YSRI) visited the University of Washington (Seattle, Washington, USA) and presented data on several Bohai Sea fish stocks that they plan to assess. One of the YSRI scientists, Mr. Yue Jin, presented available data for two commercially important squid species, *Loliolus beka* and *Loliolus japonica*. He confirmed the catch data limitations described above, and also noted that fishing effort statistics are largely limited to total vessel horsepower by year (J. Yue, pers. comm., 14 October 2019).

The task of collecting accurate catch and effort data associated with the JFS fishery, beyond the basic challenge of creating a complete system from 'ground zero', is further complicated in that the potential use of data collection from individual vessel fishery landings is compromised by a current inability to identify and verify area(s) fished per vessel trip, that may involve fishing both in domestic waters and via agreement in other countries' jurisdictions under agreement, as noted above. A number of considerable political impediments currently exist to achieving transparency and accountability related to documenting area fished for Chinese JFS landings. And given the migratory nature of JFS across national boundaries, the comprehensive development of accurate catch, effort, area fished and associated biological data necessary for assessment and ultimately to support responsive harvest controls represents a large challenge, which likely will require incremental steps over a number of years to accomplish. The initial FIP work plan has set out to tackle these issues, while recognizing the uphill challenges involved.

Another key source of information to explore further for use in monitoring and harvest strategy development is survey data. The YSRI and other China research institutes regularly conduct research surveys that quantify catches by species (g caught per hour) for approximately 40 to 60 sampling stations within the Yellow, Bohai, and East China seas (J. Yue, pers. comm., 14 October 2019). If catches of a particular species are large, scientists may subsample individuals and take body length and weight measurements. However, the data may not be regularly analyzed, and at least at YSRI, there is no designated staff or department in charge of organizing and disseminating fisheries data (J. Yue, pers. comm., 14 October 2019).

Needs for data monitoring:

- Continue and improve the research surveys
- Collect detailed (per vessel trip) data on catches, fishing effort, areas fished and associated biological data and create a system to support ongoing documentation, access, validation and analysis
- Conduct research on environmental factors related to squid abundance, including improving understanding of oceanographic influences on recruitment

The basic need to systematically collect fishery monitoring information is the highest priority in the first two years of the current FIP, and will be most valuable when collected reliably and consistently over a long period of time. One key biological parameter for ultimate assessment and management of the fishery is the size composition and maturation status of JFS in various fishing areas. The location and degree to which spawning is (or is not) occurring in Chinese fishing areas in the Yellow Sea could have considerable bearing on an approach to exploitation and escapement management. Collecting data electronically at sea could address some current challenges with identifying areas fished, and also facilitate data sharing and analysis.

Survey data collected by YSRI and other research institutes could potentially be quite valuable for improving harvest management, and an analysis of currently collected data would assist an evaluation of its practical utility for assessment and management and also lead to potential design recommendations to maximize its application. An important first step would be a description of survey methods and sample data from the research institutes and evaluation of data quality, including a gap analysis. The gap analysis could then be used to improve data collection for the purposes of monitoring squid abundance and conducting stock assessments.

For squid stock assessment purposes, it may be useful to start sampling JFS paralarvae and conduct analysis of important squid prey species, as they likely relate to JFS abundance.

Continuation of the research surveys is highly desirable and the potential for collaborating with the fishing industry to collect data could increase the capacity to conduct and refine necessary surveys. Analysis outputs, including stock assessments, are of interest to the fishermen and developing regular avenues for sharing information could create incentives for collaboration.

Because of the high correlation likely between JFS recruitment and environmental factors, scientific research at government research and academic institutes tailored to improve understanding of the environmental and ecological drivers of squid abundance and productivity would be very useful for management (Agnew et al. 2005). The review and evaluation of current survey work discussed above could facilitate the design of additional research toward meeting this objective, including how it could specifically facilitate forecasting, assessment and harvest strategy development.

Stock assessment and reference points

JFS stocks are not regularly assessed by Chinese entities, although a few stock assessments have been conducted in the past (Ocean Outcomes 2016). Additionally, the Fisheries Research and Education Agency of Japan (FRA) conducts annual assessments for the fall and winter JFS stocks. There are no management reference points for these stocks. Specific management objectives and reference points will ultimately be needed to design and evaluate harvest strategies, which stock assessments will support, but the initial priority is for improved estimates of biomass, distribution and key life history parameters. Potential actions related to stock assessment include the following:

- Start conducting stock assessments of JFS with objective of estimating biomass, biomass indices and exploitation rates;
- Ultimately work towards collaboration with other parties fishing these straddling stocks (e.g. Japan, South Korea) in terms of data exchange;
- Iteratively evaluate potential approaches to establishing management objectives and reference points given results of initial assessments, so they may be further tailored to work together as part of an overall harvest strategy.

The case studies evaluated above identify a number of potential approaches to establishing biomass and fishing mortality reference points, as well as responsive harvest strategies, which can help inform potential application for the Chinese JFS fishery. Initial stock assessment work should have an explicit intent to refine a conceptual 'operating model' that deepens the general understanding of the JFS migration characteristics shown in Fig. 4. From a practical standpoint, initial assessment and management approaches that can facilitate domestic Chinese management needs while beginning to define the opportunities for interjurisdictional collaboration will be most valuable. This idea also ties into the monitoring discussion above given that differentiation of JFS catch, effort, area fished and biological data for Chinese landings will be a prerequisite for establishing rational management objectives, biological reference points and harvest strategies.

At the same time the consideration of different types of management objectives would help focus assessment and data collection design. For example, one management objective may be to allow for adequate escapement (adequate spawning biomass) to support future recruitment. To meet this objective, there needs to be an understanding of whether Chinese JFS catches in the Yellow Sea largely consist of juveniles, or whether there is a significant degree of spawning that occurs, and how this is affected by time and area. Stock reference points to achieve these management objectives can then be developed and considered within the stock assessment. For instance, some squid stock assessments estimate $F_{\%SPR}$ reference points to allow for adequate spawner escapement (Hendrickson 2017), where $F_{\%SPR}$ is the fishing mortality at a certain spawning potential ratio (ratio expressed as a percentage).

Conducting assessments of the JFS fall and winter stocks in Chinese waters is essential for ultimately developing responsive harvest management and evaluating management performance. Regularly conducting assessments and communicating their results will also help build industry's confidence in the management system as active management begins to be established, and could lead to refinement of the current summer fishing moratorium that better reflects the needs for harvest access and conservation in Chinese domestic waters. Fishers want to know the status of the stocks they depend upon. The long-term goal certainly should be for these assessments to be conducted in collaboration with Japanese and Korean research institutes, and it is not too soon to begin to strategize how current political interests and sensitivities might be overcome to encourage increasing collaboration.

As described in the case studies above, squid stock assessments are challenging since they must detect significant changes rapidly, while balancing data collection needs with the costs of data acquisition (Arkhipkin et al. 2013). Management must evaluate scientific advice and proceed with decisions quickly to meet stock conservation targets. In the case of China's JFS fishery, starting with relatively simple stock assessment models may be a more acceptable way to start incorporating regular stock assessments into management. A variety of data-limited stock assessment methods, such as catch or length-based methods, might be useful. In other management systems, squid assessment methods that have been used include depletion methods, swept area methods, and acoustics (Arkhipkin et al. 2015). The most appropriate method will depend on the type(s) of data that are available for JFS.

One potential approach is depletion methods, which are commonly used to evaluate cephalopod stock abundance (e.g. Royer et al. 2002). This type of method involves modelling the depletion of a stock during the main fishing season and analyzing the influence of cumulative fishing effort on an abundance index, allowing for estimation of the total initial stock size for that season (Leslie and Davis 1939). Put more simply, depletion methods often use CPUE (catch per unit effort) data and life history information to estimate fishery status relative to reference points. Depletion-type models assume a closed population (e.g. no immigration), constant catchability over stock size and time, and no target switching by fishermen within time. Squid fisheries usually violate these assumptions (Keller et al. 2015), but adjustments can sometimes be made using monitoring data, e.g. adjusting for immigration of squid from other cohorts or populations into fished areas. Depletion models can be compatible with in-season assessment of individual cohorts or spawning groups (Agnew et al. 2005).

Harvest control rules and management actions

China's JFS fisheries currently lack harvest control rules (HCRs) and fishery specific harvest management actions. There are input controls in terms of requiring licenses for fishing vessels, and the summer fishing moratorium. Before a meaningful harvest strategy and control rules can be established for domestic waters, a better understanding of trade-offs between fishery access and conservation benefits is needed

Needs for harvest control

- Evaluate relationship of the summer moratorium to fishery access and conservation of JFS in Chinese domestic waters;
- Develop mechanisms to trigger fishery closure if indicators suggest that resource is at a low level;
- Hold stakeholder consultations.

For short-lived species such as squid, management through fishing time and area controls are very common (Dichmont et al. 2006). Such controls apply in the case of the China JFS fishery as well. The summer fishing moratorium, which is relatively straightforward to implement and enforce, is currently the primary means of limiting fishing exploitation on JFS stocks from Chinese fisheries. However, the moratorium currently prevents meaningful fishery access to JFS by Chinese vessels in domestic waters simply due to migration timing. Once more refined biomass, timing and maturity data can be developed, a simple management strategy evaluation would help evaluate the trade-offs between different time-area and active management strategies toward meeting rational harvest and conservation objectives.

Some future considerations regarding additional or refined management controls on squid harvests should include approaches adjusted based on abundance monitoring, such as quotas, catch limits and/or CPUE indices. There are several options for setting catch limits. From an ecological perspective, allowing a certain proportion of adults to escape the fishery would help maintain stock abundance, since a certain level of spawning activity is needed to sustain the population. At this stage, estimating spawning biomass to set escapements is not particularly feasible. One alternative, demonstrated by the case of California market squid, is to use historical catch data to set a catch limit. Such data are lacking for the China JFS fishery but could start to be collected. However, current catch levels are unlikely to be precautionary since the squid stocks have been heavily exploited for many years. In addition, there is insufficient evidence to suggest that current harvest levels are sustainable; of concern is the fact that catches have been low from 2016 to 2018, according to Japanese stock assessments. Limits based on recent catch information therefore might be developed in a precautionary manner, for instance by applying a buffer so that the catch limit is below recent mean catch levels.

Another option is to use a pre-season research survey to make some type of pre-season management prediction and set an appropriate harvest level. This option would require additional monitoring and data analysis, including better understanding of the factors linked to the JFS abundance. An advantage of this option is that it would be more directly linked to the state of the stock than historical catch data.

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