FISHERIES MANAGEMENT AND RESEARCH FOR *LOLIGO GAHI* IN THE FALKLAND ISLANDS

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ABSTRACT

Two squid species have been the subject of targeted fisheries in the southwest Atlantic since the early 1980s. The two fisheries have been managed in Falkland Islands waters since 1987 and provide an annual license revenue to the Falkland Islands government equivalent to some $35 (U.S.) million. The real-time assessment of the two species, *Loligo gahi* and *Illex argentinus*, is based on the Leslie-DeLury assessment model. The model assumes a single recruitment event before the start of the period used in fitting the model, and a closed population during the period. Early research on the demography and distribution of the Falkland Islands *L. gahi* population demonstrated ontogenetic descent with a probable associated coastward spawning migration. The *L. gahi* fishery concentrates by area and does not follow the migration pattern, indicating that the closed population assumption of the assessment model is invalid for much of the period assessed. Research has confirmed the variable nature of recruitment of microcohorts to the fishery, overstretching the single-recruitment assumption of the Leslie-DeLury model. But research has also shown that there are periods of residency of *L. gahi* on the fishing grounds. The current assessment procedure uses these periods of residency to derive estimates of population depletion and therefore stock size. In this paper the salient features of the fishery for *L. gahi* are presented, and the crucial links between resource assessment, biological research, and management advice are discussed. Finally, directions for further research, needed to refine assessments and achieve some predictability of population processes, are identified.

INTRODUCTION

The productive waters of the Patagonian Shelf around the Falkland Islands support two major squid fisheries and four finfish fisheries. February 1997 marked the first decade of controlled fishing effort management by the Falkland Islands government. In this paper, we present the salient features of the fishery for the Patagonian squid (*Loligo gahi*) by describing the management procedure, followed by the population ecology of *L. gahi*. We then discuss the crucial links between resource assessment, biological research, and management advice. Finally we identify directions for further research to refine assessments and achieve some predictability of population processes.

This paper reviews the biological research carried out to date, and shows how knowledge of the exploited *L. gahi* population has been used to produce the currently held life-history model that serves as the basis for the assessment.

MANAGEMENT

The completion of the first ten years of the Falkland Islands Fisheries management regime provides a timely opportunity to describe the underlying policy and to review some statistics.

Fisheries Policy

From its beginning in 1987, the three objectives of the fisheries policy have been (Anon. 1989):

1. to conserve the resource,
2. to maintain the fisheries' economic viability, and
3. to enable the Falkland Islands to enjoy greater benefit from the resource.

Licenses. Licenses and license fees were introduced as policy measures to limit access to the different fisheries and to raise revenue for assessment, research, management, and enforcement of the fisheries policy.

From 1987 to 1990, access to the fishery for *L. gahi* was through a dedicated "squid south" license from February to June. This separated *L. gahi* vessels from those fishing for the short-finned squid (*Illex argentinus*) under a "squid north" license. Initially both licenses allowed the catch of finfish as well as squid, but restricted vessels to grounds either north or south of 51°20' south latitude.

There has been little overlap between fleets fishing for the two species over the years. The oceanic squid *Illex argentinus* migrates with the Brazilian Current from approximately 45° north latitude on the high seas some 200 miles off the northern Argentinean coast, through the Argentinean Exclusive Economic Zone, down through the northern half of the Falkland Islands fishing zones, and then back north again. In Falkland Islands

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waters, *I. argentinus* has been pursued mainly by jigging vessels attracting feeding aggregations to the surface with powerful lights at night, between January and June.

By contrast, *Loligo gahi* is found in greatest densities only from the northeast (south of 51°20'S) to the south of the islands, in the Falkland Islands Conservation Zone, within 100 nautical miles of the islands (fig. 1). *L. gahi* is a colder-water demersal squid, smaller than *I. argentinus*. It has been pursued by trawlers targeting concentrations near the seabed on the edge of the continental shelf during daytime. Jigging vessels are unlikely to catch finfish species, but demersal trawlers can easily catch finfish and *L. gahi* with no change of gear. In order to avoid the risk of gear interactions between *L. gahi* and finfish fisheries throughout the year, in 1991 a specific *L. gahi* license was created for the second half of the calendar year.

Licenses are usually issued for individual vessels and for one season only, but long-term involvement has been encouraged through 5-year licenses in one or both seasons. "Long-term" licenses for *L. gahi* are awarded to vessel owners contributing to the development of the local fishing industry, according to criteria periodically defined in the fisheries policy. The total allowable effort in "vessel-capacity-units" is determined from an assessment of spawning stock escapement of the previous year, as described later in this paper. Within the estimated total effort, allocation to individual vessels is at the discretion of the fisheries director of the Fisheries Department of the Falkland Islands Government (FIGFD), and follows a ranking of applicants according to a point system published as part of the fisheries policy. The point system formalizes some requirements of the third objective of the fisheries policy by giving an advantage to applications which entail direct commercial involvement of Falkland Islands residents and businesses.

The basis for license fees applied to trawlers is the international gross registered tonnage (IGRT), a measure of the volume displacement of the vessel on the water. In the *L. gahi* fleet, the IGRT provides a very good correlate of vessel length (and beam by definition) and also of engine-brake horsepower and volume of freezer holds (des Clers and Hudson, unpubl. data). Twice a year, the Falkland Islands government publishes (in the official gazette) the terms and conditions, including fishing license fee, that will prevail for the next six-month season. A license fee for the whole season is a linear function of a vessel's IGRT. The coefficients of the fee policy formula are revised, through an analysis of individual vessel production (tonnage and estimated gross value), at the end of each season.

In 1996, 61,360 tonnes of *L. gahi* were caught, and the revenue generated from license fees for *L. gahi* was 4 million pounds sterling (approx. 6.2 million U.S. dollars). This represented about 28% of the total revenue from all squid and finfish licenses (Falkland Islands Government 1997). Assuming an average market price of \$900(U.S.)/t of *L. gahi* to vessel owners, this means that an estimated 7% of the fisheries gross revenue was extracted as license fees.

Closed seasons. The fishery for *L. gahi* is currently licensed as two separate fishing seasons, from February to May and from August to October. The seasons were originally chosen to cover the peak of early 1980s commercial catches by Russian, Polish, and Spanish vessels (Csirke 1987; Patterson 1987, 1988; des Clers 1998a). This is still the case in most seasons, when the squid migration through the fishing grounds is entirely framed by the seasons' beginning and end dates. However, fixed dates have served to control fishing mortality on several occasions, which are described in detail in Resource Assessments later in this paper.

An important feature of the management regime is that the fisheries director may decide to close the season early, as a result of real-time catch and effort monitoring and stock assessment throughout the season. This happened once in the first ten years of the fishery. In 1989, the first season, which originally lasted (albeit at a reduced pace) until June, was closed three weeks early at the end of May. The first season's duration has been four months ever since.

Closed areas. Since 1990, the fisheries policy has specified grounds reserved to *L. gahi* fishing. The "Loligo box" extends over some 9,700 square nautical miles. It covers the entire fishing grounds for *L. gahi* on the shelf edge around the islands from the north-northeast of East Falkland to the south of West Falkland (fig. 1). The original purpose of the Loligo box was twofold. The main purpose was to keep trawlers licensed to catch finfish out of the squid fishery. This has been very effective; exemptions have been granted rarely and only to semipelagic trawlers targeting spawning aggregations of southern blue whiting (*Micromesistius australis*). The second purpose was to confine vessels targeting squid, for which there are no prescribed minimum mesh sizes, to fishing grounds where there is the least likelihood for incidental capture of juvenile finfish.

The fishery is conducted in the 80–300 m depth range, but most catches are concentrated along the shelf break at depths between 150 and 200 m. This is a much narrower depth range than that in which the species is found around the Falkland Islands (some 20–400 m; Hatfield et al. 1990).

Some areas are explicitly closed—to certain vessels or to license types or at certain times of the year—by the fisheries conservation policy. An even larger area, however, is currently closed to fishing because there are no coastal fleet or small-scale, local, sea-fishing activities.

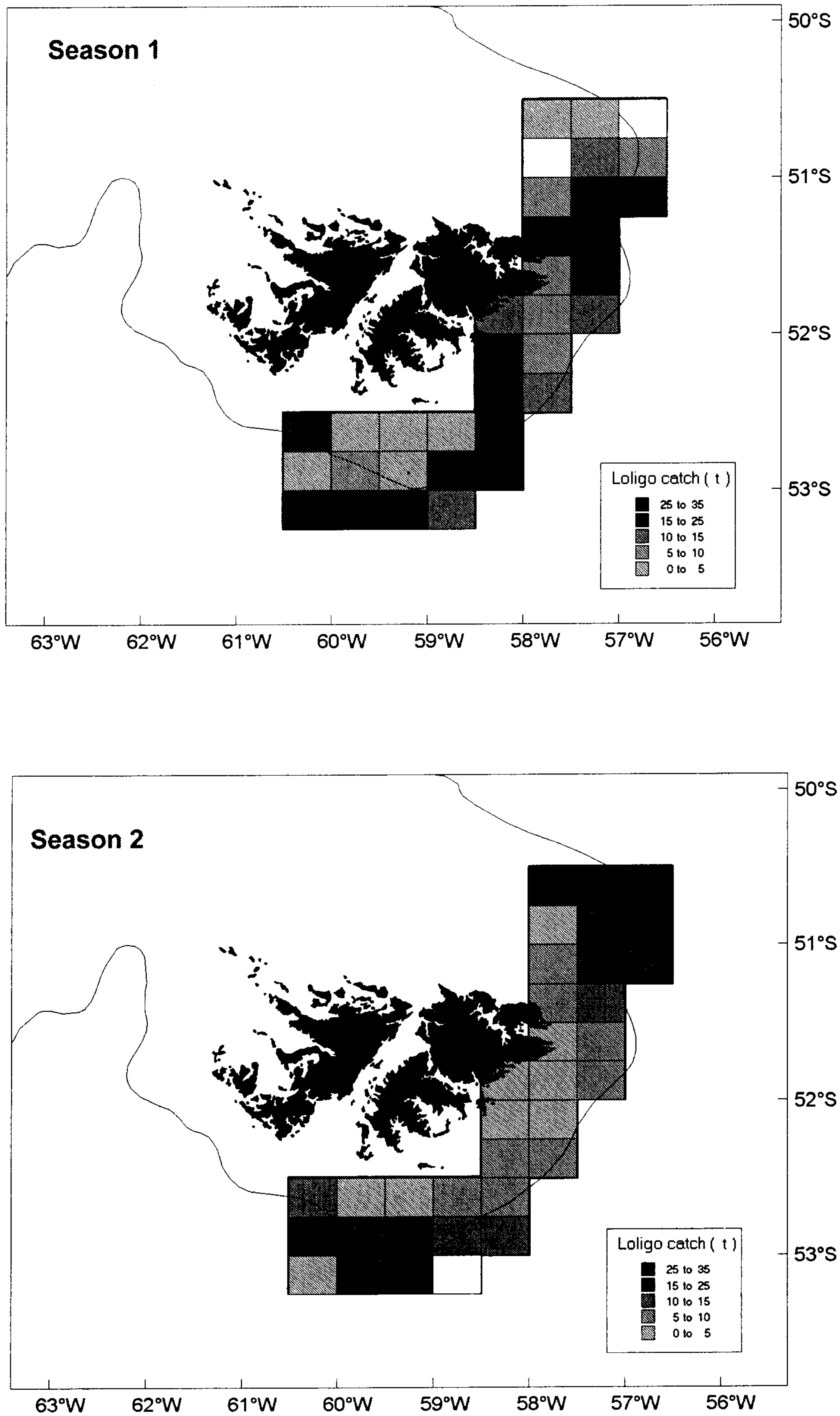

Figure 1. *Loligo gahi.* The "Loligo box" and areas of highest commercial activity in relation to catch season and bathymetry (200 m isobath) around the West (left) and East (right) Falkland Islands.

Therefore, most of the depth range of coastal habitat, between 20 and 100 m, is de facto in a marine protected area because the grounds are not suitable to the current fleet of large factory trawlers.

Other technical conservation measures. There is no other limitation on inputs apart from vessel licensing, closed seasons, and closed areas in the fishery for *L. gahi*. For instance, there is no mesh size or other gear prescription. In terms of output control, there are no minimum landing sizes or specifications for bycatch or discards, but the processing of *L. gahi* into meal is prohibited in all fisheries licensed in Falkland Islands waters.

Fisheries Statistics

The small population and limited scope for rapid onshore infrastructure development on the Falkland Islands in 1987, and the distant operating area of the fleet, meant that output (landings) would have been very difficult to monitor. This was the essential reason for the choice to limit input as a management regime.

From the outset, it was also recognized that the *L. gahi* fishery operated on a short-lived species (Anon. 1989). This meant that management decisions might be needed during the fishing season. In order to build the necessary information base, the FIGFD launched an intensive data-collection exercise as part of the fishing license requirements. This program is still in effect, and includes radio transmission to the FIGFD of detailed information about individual vessel position and catch and effort. Technical details about vessels are gathered at the license application stage, and biological information is collected by scientific observers placed by the FIGFD on board selected vessels.

Catch. Between 1987 and 1996 an annual average of 75,000 tonnes of *L. gahi* was caught in Falkland Islands waters (Anon. 1989; Falkland Islands Government 1997; table 1). These were the highest annual catches of loliginid squid worldwide until 1996, when the fast-developing fishery for California market squid (*Loligo opalescens*) produced 80,272 tonnes (Vojkovich 1998).

A characteristic of squid fisheries is a large interannual variability in fishable biomass (Boyle 1990; Boyle and Boletsky 1996). This is not surprising, given the potentially stronger effect of environmental fluctuations on marine species with short life spans and extensive migrations.

In Falklands Islands waters this variability is reflected by coefficients of variations of annual catches of 29% for *L. gahi* (average catch 75,309 t) and 42% for *I. argentinus* (average catch 136,858 t; table 1). A greater variability of total annual catches for oceanic species compared to demersal squid species has been noted before on the east coast of the United States (*Illex illecebrosus* and *Loligo pealei*, Dawe et al. 1990).

TABLE 1
Historical Catch Figures in the Falkland Islands Squid Fisheries

	Loligo gahi			*Illex argentinus*	
Year	Total annual catch (t)	% annual catch/ average	% catch 1st season/ annual total	Total annual catch (t)	% annual catch/ average
1987	82,547	110	78	142,051	104
1988	53,931	72	90	209,523	153
1989	118,720	158	90	224,022	164
1990	82,990	110	84	102,417	75
1991	53,817	71	69	174,745	128
1992	83,384	111	58	160,016	117
1993	52,279	69	45	145,160	106
1994	65,757	87	54	66,996	49
1995	98,308	131	62	63,843	47
1996	61,360	81	63	79,803	58
Average	75,309	100	69	136,858	100
COV	0.29	0.29	0.23	0.42	0.42

Reported catches are not equivalent to population abundance (the details are discussed later in the paper through an analysis of differences in fishing effort and catch per unit of effort between years). However, catches, which reflect both global population abundance and local availability (itself a function of effort and migrations), may be less variable in squid when demersal feeding aggregations are harvested. The higher apparent stability of targeted feeding aggregations may be expected to break down when the fishery exploits spawning aggregations. Such breakdowns may be seen as either large interannual fluctuations in catch, such as for *Loligo opalescens* on the U.S. west coast (Yaremko 1997), or intra-annual differences, such as for *L. vulgaris reynaudii* off South Africa (Augustyn et al. 1992). Environmental cues such as temperature, current, and turbidity, which are known to influence spawning migrations (Roberts and Sauer 1994), are more likely to vary rapidly and to a greater extent on inshore, shallow spawning grounds than on offshore, deeper feeding grounds. Nonetheless, on the U.S. east coast it seems that the offshore fishery targeting feeding aggregations of *L. pealei* is more variable than the inshore fishery targeting spawning aggregations (NEFSC 1996).

Large interannual variations in total catches have nevertheless been a feature of the Falkland Islands *L. gahi* fishery, and have prompted in-season management decisions on several occasions. Between 1987 and 1996, production ranged between a low of 52,000 t in 1993 and a high of 119,000 t in 1989 (table 1). These variations resulted in adjustments of effort allocation and consequent fluctuations of fee revenues. In its first ten years, the fishery has established and monopolized a predominantly European market. Therefore market prices have often been inversely related to production, and fee policies have had to be appraised in depth before each new fishing season.

Effort. The fishing fleet targeting *L. gahi* in Falkland Islands waters has always been made up of large factory trawlers (West European and initially some East European). Fleet composition, license allocation, and details of changes over the first ten years of the regulated fishery are given in Anon. 1989, Falkland Islands Government 1997, and des Clers 1998b.

Several types of fishing effort descriptors are used routinely in the Falkland Islands *L. gahi* fishery. Weekly averaged numbers of hours fished per day are used to assess the resource. Maximum allowable fishing mortality estimated from assessments is then translated into allowable effort in terms of maximum fleet aggregate tonnage. The total allowable fishing effort is distributed among individual applicant vessels during the licensing exercise. Individual tonnage (IGRT) is the only vessel detail currently used in the fee policy equation. But a wealth of other data collected through the biannual license application rounds are updated into a computerized database at the FIGFD, and routinely checked by fisheries inspectors. Vessel details are also studied through statistical analyses of daily catch rates, and by scientific observers.

An important feature of the *L. gahi* fishing fleet is that average individual vessel size (1,500 IGRT) has remained constant over the years (des Clers 1998b). Total fleet size has decreased, but this does not imply a decrease in fishing effort, because the fewer vessels have fished more during the season. Thus the decrease in total number of vessel-days fishing in the first season has been compensated by an increase in the second season (des Clers 1998a). Furthermore, record catches of 1995 (98,308 t), when compared to those of 1989 (118,720 t), suggest that gradual technological upgrades—whether in finding, catching, or freezing efficiency—have most likely made up for reductions in numbers of vessel-days and hours fished.

The spatial and temporal distributions of fishing activity lend two further dimensions to the matter of effort. In essence, the fixed duration of the two fishing seasons, and the confines of the Loligo box combine to create a narrow window in space and time through which the squid migrate. This creates an intrinsic link between migration and abundance on the fishing grounds. An early migration, for example, may be well under way by the time the fishing season starts at week 5 (first week of February). This is illustrated by the CPUE (catch per unit of effort) time series in the 1990 and 1995 first seasons or in the 1992 and 1993 second seasons (fig. 2). Therefore the fixed frame of the window determines a "perceived abundance," which may in some years be quite different from the actual size of the population moving through the fishing grounds and surviving a fishing season.

Although this difference is not obvious every year (see discussion of CPUE below), it is likely that the bulk of the squid exploited in the first season and the bulk in the second season come from two separate cohorts. Prevailing wisdom considers the population to be homogeneous throughout the Loligo box (Agnew et al., in press), but a recent hypothesis suggests that the two fishing areas support two reasonably distinct populations (Nolan et al., in press).

Scientific Observer Program

The limited-entry management regime chosen by the FIGFD in 1987 relied on the possibility of limiting mortality by closing the fishing season before its usual end if necessary. The decision for a possible early closure is based on evidence from assessments of the squid fishable biomass, or stock size, which is derived from a basic population dynamics accounting exercise on estimated squid numbers. (Details of the stock assessment technique are discussed in the later section Resource Assessments.) Information is collected routinely on squid size, sex, and maturity in order to follow population processes, and on individual weights in order to translate daily catches (tonnes) into numbers of squid.

The data are collected by FIGFD scientific observers who stay on board vessels for three to five weeks at a time to monitor daily catches, effort, and biological parameters. The fishery for *L. gahi* has been the most observed of all Falkland Islands fisheries; for example, in 1997 there were 310 observer-days during the 27-week total duration of the two fishing seasons. In 1997, 132,000 *L. gahi* were measured (equivalent to some 14.8 km) and dissected to determine sex and maturation; a further 7,345 were taken back to shore to be weighed.

In addition to monitoring the fisheries, scientific observers contribute to various collaborative research projects, including squid taxonomy; studies of world bycatch and discards; and surveys of birds and marine mammals. Their observations and activities, described in reports kept by the FIGFD, provide crucial insight for the stock-assessment exercise.

Catch per Unit of Effort

Catch per unit of effort (CPUE) time series statistics are very different data from all of the above in that they are a mathematical construct. There is no such thing as CPUE in the real world; CPUE exists only in terms of fisheries assessment. For this reason, and because CPUE is a ratio and therefore does not vary linearly with either catch or effort, CPUE time series must be interpreted with caution.

These points are examined in detail in the later section Resource Assessments, which discusses theory and practice. However, it is important to keep them in mind, notably when reading about past research and future

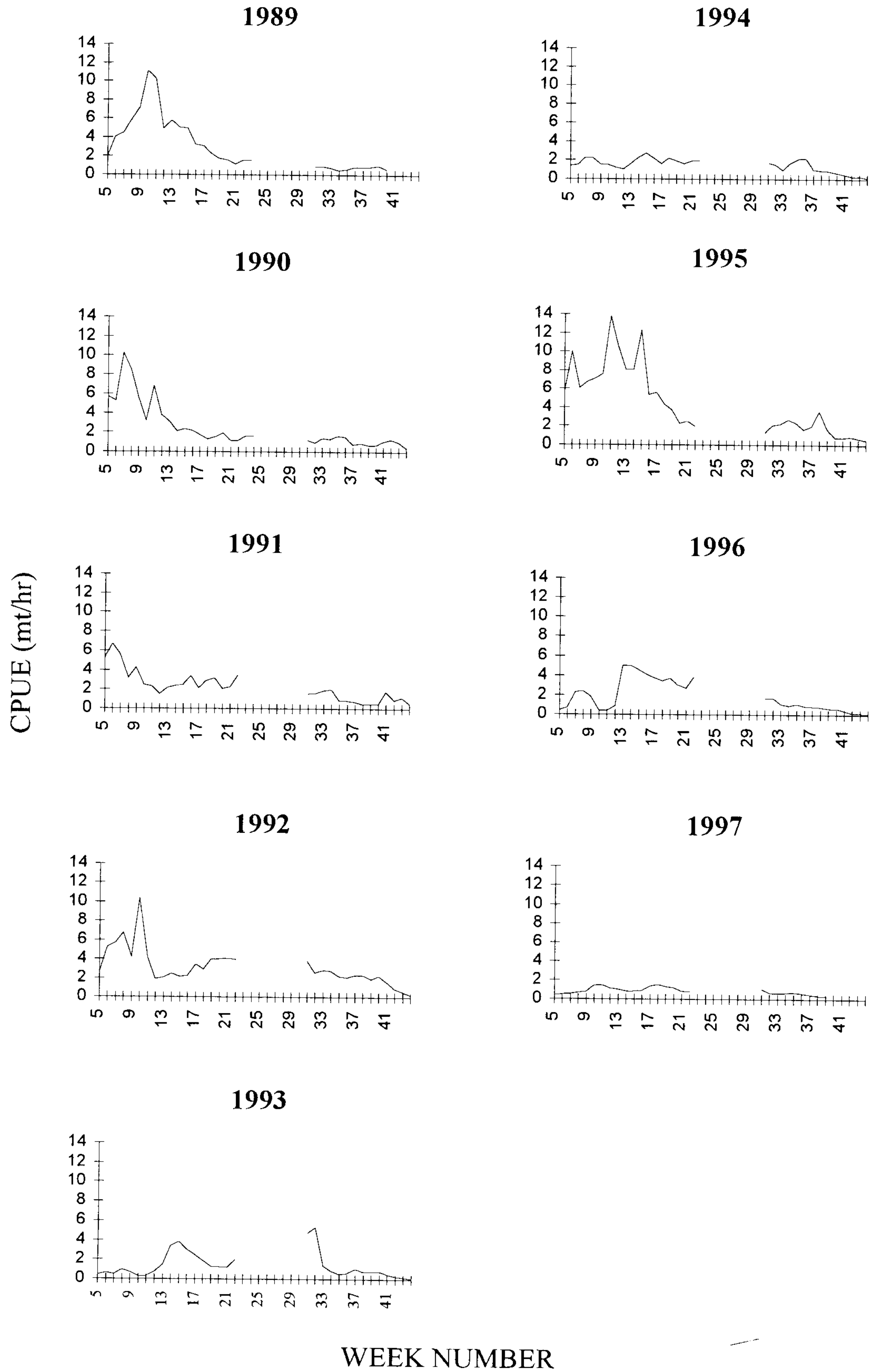

Figure 2. *Loligo gahi.* Patterns in catch per unit of effort (CPUE, tonnes per hour trawled) from 1989 through 1997 in season 1 (week 5 to around week 22) and season 2 (week 31 to end).

needs. Nearly all data on which research has been based so far have been collected from samples taken from the commercial fishery.

RESEARCH

The role of research as an essential pillar of fisheries management has been recognized from the start in the *L. gahi* fishery. In an effort to provide the best possible biological information for assessments and management advice, research thus far has concentrated on the dynamics of the exploited population.

Beyond the need to define priorities, the FIGFD has had to address a less common challenge. Research, which had to be wholly contracted out overseas because of lack of local human resources, had to be steered in ways that allowed a gradual transfer to local development.

The British government, prior to February 1987, commissioned some (unpublished) expert consultations, mainly to evaluate alternative fisheries management regimes for the Falkland Islands (J. Beddington, pers. comm.). Research programs were effectively initiated in 1987.

Population Biology

Population structure. Patterson (1988) made the first attempt at estimating the growth of *L. gahi* and disentangling the population structure of multiple cohorts observed in the two fishing seasons. Using length-frequency and maturity data from samples of commercial catches, he proposed that the exploited *L. gahi* resource comprised two separate stocks, each with an annual life cycle. These stocks were hypothesized to recruit to the fishery in March and November. The stock recruited in March was harvested in the first season (February to May–June) and the second season (August to October). The second stock, recruited to the (closed) fishery in November, was available to the fishery in the first season alone. Thus the presence of two stocks in the first season explained the higher abundances seen in March and April, whereas lower abundances in the second season were explained by the presence of a single stock.

Population structure was further researched through an analysis of the population genetics of the Falkland Islands *L. gahi* population (Carvalho and Loney 1989; Carvalho and Pitcher 1989). The samples analyzed came from commercial catches, notably in the north and south of the Loligo box, and from both seasons. Electrophoretic evidence did not confirm the existence of the discrete stocks proposed by Patterson (1988), although the life-history parameters, such as size and maturity, collected as part of the genetics study confirmed the Patterson (1988) two-stock hypothesis. The population genetics study concluded that genetic evidence favored the existence of a single, interbreeding population of *L. gahi*, and suggested that the lack of genetic evidence for discrete stocks could be due to a combination of migration and extended spawning period for males. An analysis of the population's age structure was recommended to help resolve the issue of stock structure.

Migrations. The geographical distribution and likely life-cycle migrations of *L. gahi* were first mapped during an extensive dedicated research survey in 1988. The survey suggested that *L. gahi* migrated from shallow coastal spawning/nursery grounds into the deeper waters of the continental slope and shelf edge as they fed, grew, and matured, and that there was a probable coastward return migration (Hatfield et al. 1990; fig. 3). Highest feeding concentrations of squid appeared to occur at depths and in areas of the Loligo box where the commercial fishery concentrated its activities.

The extensive survey coverage demonstrated that narrow size ranges of *L. gahi* were associated with narrow depth ranges, and that larger squid were found in deeper waters. This explained the enigma of the apparently constant size of *L. gahi* caught by the commercial fishery during parts of the fishing season, because vessels were focusing on narrow depth ranges. The migratory nature of *L. gahi* also meant that peaks of CPUE in the commercial fishery could be due to pulses of squid moving either offshore to the feeding grounds or inshore to the spawning grounds.

Age and growth. Concomitant research to assess the age structure of the population by using both research and fishery samples (Hatfield 1991) confirmed the hypothesis of the annual life cycle and demonstrated the presence, by back-calculation, of two major peaks of hatch in August/September and December/January. These peaks probably cause two of the major peaks of recruitment, seen as increases in CPUE in February and May, because squid appear to recruit between five and seven months of age.

These initial age data did not explain the changes in CPUE observed in the second season, nor did they agree entirely with the brood structure description of Patterson (1988) and Carvalho and Pitcher (1989). However, these early pieces of research demonstrated that stock assessments could be invalid if interactions between migrations, growth, and population structure were not accounted for. They also showed how further biological research held the key to understanding the structure of the *L. gahi* population in Falkland Islands waters.

A later, more detailed, age study linked migrations to growth of individual broods (Hatfield and Rodhouse 1994a) and suggested periods of residency on the fishing grounds. This study made it possible to determine rates of growth more accurately than had previously been possible (Patterson 1988; Hatfield 1991). The study's findings about migrations have been reinforced by a re-

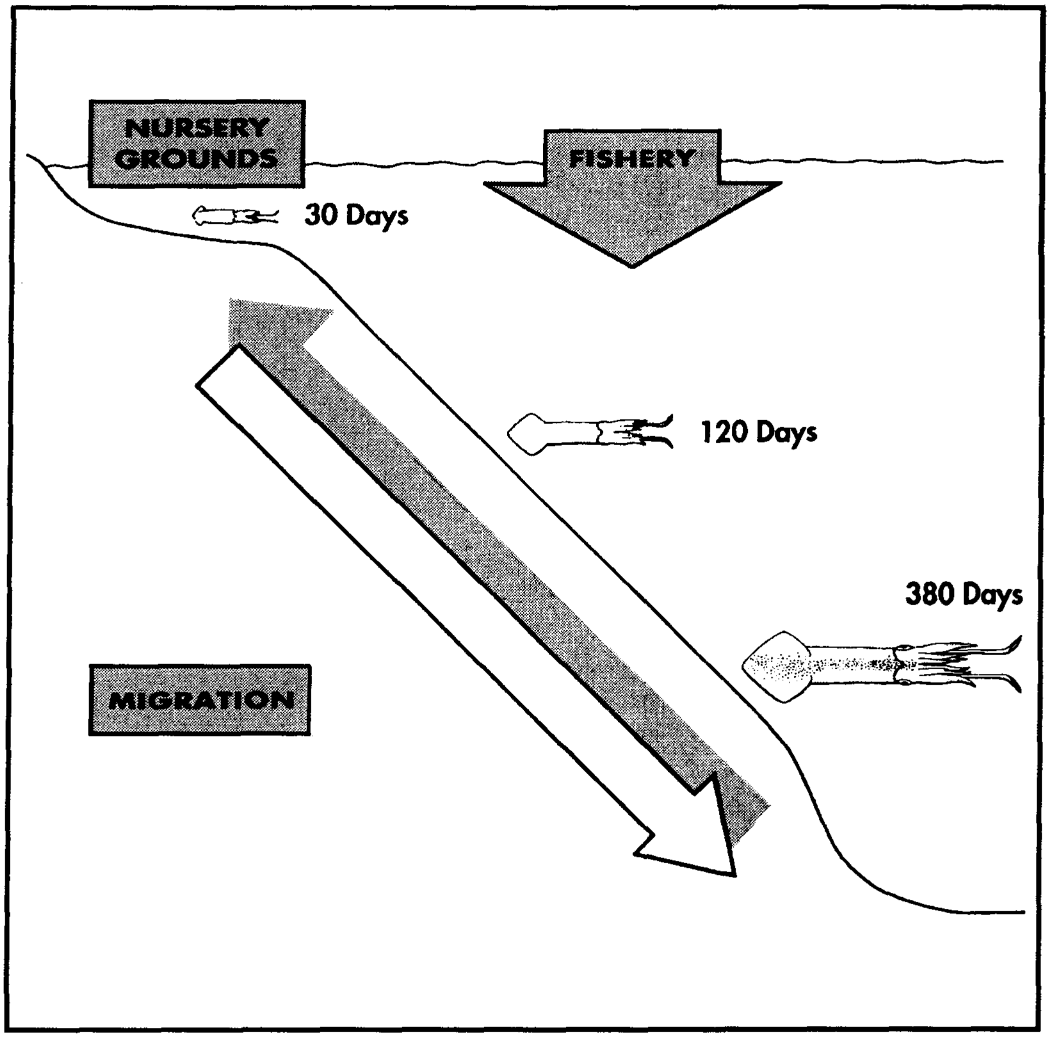

Figure 3. *Loligo gahi.* Diagram depicting migrations over the Patagonian Shelf and the association with the commercial fishery (reproduced by permission of *Antarctic Science*).

cent analysis of length, weight, and maturity data from the commercial fishery, which has confirmed the highly variable pattern of immigration and residency throughout the year (Agnew et al., in press).

Early life history. Data on the early life history of *L. gahi* cannot be collected from the commercial fishery because squid are usually caught only in the second six months of the life cycle.

Four research surveys around the Falkland Islands, employing small research nets generally inshore from commercially fished areas, were conducted between 1988 and 1992 in the austral winter and spring. Reasonable numbers of paralarvae and juveniles of *L. gahi* were caught (Hatfield and Rodhouse 1994b), corroborating the presence of one of the broods seen in the first commercial fishing season and demonstrating the presence of a third brood of squid rarely present in commercial catches, or then only late in the second season.

Life cycle. The research data on early life history, together with growth rates estimated from age studies, were combined to produce a life-cycle model (Hatfield and Rodhouse 1994b). The model proposed that the exploited population usually comprises three broods.

The two major peaks in CPUE in the first season are produced by the immigration of a first and a second brood. The first peak in the second season is due to the continued presence of the second brood from the first season, which for some reason is unavailable to the fishery from June to August. The second peak in the second season, which is not apparent in commercial catches every year, is produced by immigration of a third brood. The proposed third brood corresponds with the brood originally described by Patterson (1988) and Carvalho and Pitcher (1989) as recruiting in the austral spring.

Data analyses of mean length for successive maturity stages and relative proportions of each maturity stage in the population at monthly intervals between 1987 and 1991 provided further evidence of three broods in the population, and confirmed the supposed pattern of entry of each brood into the commercial fishery (Hatfield 1996).

The three-brood hypothesis explains the early genetic findings about panmixia within the exploited Falkland Islands *L. gahi* population, particularly because each of the three major broods can recruit over a relatively extended and variable time period. This may result in a steady trickle of recruitment throughout a large part of both fishing seasons, as evinced by a year-round hatching pattern (Hatfield 1991). More recent age data (as yet unpublished from samples taken in 1994 and 1995) continue to show only two peaks of hatch. The lack of an identified peak for the third brood, likely to be in May, could simply reflect the relatively smaller size and unpredictable occurrence of this brood.

Resource Assessments

Since 1987, the *L. gahi* fishery has been assessed with a modified Leslie-DeLury model originally developed for the Falkland Islands *Illex argentinus* fishery (see Rosenberg et al. 1990; Basson et al. 1996).

The beauty of the technique is its simplicity. As the population is depleted and total catches accumulate, the CPUE decreases. The heart of the assessment is a log-linear regression estimation problem. In the routine assessment for *L. gahi*, input data are the time series of weekly catch, effort, and total catches, and a fixed natural mortality over the period. Provided one has at least three weekly data points, it is possible to estimate the size of the initial population and the vessels' ability to catch, which is assumed to remain constant over the period.

In practice, the analysis is done by subfleet, each assumed to deplete the same population, but each with a separate catchability coefficient. This means that catch and effort data must be available for each group of comparable vessels within the fleet. Also assessed are squid numbers, which are estimated from the tonnage caught on the basis of length-frequency distributions, weight at length by sex, and sex-ratio data. The population data are collected by scientific observers.

Simplicity is conditioned by a few key assumptions. The most basic Leslie-DeLury condition to obtain valid estimates of the initial population size and rate of depletion is that the population is "closed." Closure has to be both demographic (no birth or death) and geographic (no migrations in or out), but only over the period and area of assessment.

The assessment model has been adapted for squid to account for migrations (Brodziak and Rosenberg 1993; Basson et al. 1996; Agnew et al. 1998). However, research has not yet offered a way to define what a *Loligo gahi* population is, let alone to assume that it is closed at any place or time. In particular, a better understanding of what makes a brood or cohort within the fishery and what determines a given brood to replace another is needed, as well as the relative proportions of each brood that are present at the swap-over period.

Although some operational modifications of the assessment procedure have recently been suggested (Agnew et al. 1998), we currently have no predictive understanding of the population processes at play. The exploited *L. gahi* resource is presumed to be one population during the course of a season, and homogeneous throughout the Loligo box (Agnew et al., in press) despite some signs of a north-south divide (Nolan et al., in press). Seasonal assessments still derive very much from an *ad hoc* procedure invoked mostly a posteriori. Their main purpose is to estimate the subfleet catchability coefficients necessary to determine total allowable effort for the following year.

Management Advice

Since 1987, the essential biological assessment management advice has been the determination of total allowable effort. This is carried out for each season based on the assessment of the same season the previous year. The patterns of migration and depletion are analyzed. Initial abundance (and final escapement) and subfleet catchability coefficients are estimated when possible and compared to estimates for the same season from previous years. This is described in some detail in Agnew et al. (1998).

Although early closure has always been an option, it was only considered once in the first ten years of the fishery, in 1991, and for a second time in 1997, when first-season catches were very poor. In each case, projections of conventional stock-assessment estimates indicated a low final percentage escapement from the fishery. In both cases scientific advice proved difficult to formulate, mainly because two broods or cohorts were present in the first season, and because a poor recruitment in the first season does not imply the same for the second season. Halfway through the first season, around week 13 (fig. 2), real-time daily monitoring yields very little information about total catch or CPUE for the coming eight weeks (see figs. 3 and 5 in Agnew et al. 1998).

Originally, the management target was a 40% escapement of the biomass estimated in the absence of fishing. In practice, although this target has been a useful guide, absolute escapement would be a more useful target. It remains impossible to set an absolute escapement target until more is known about *L. gahi*'s population structure and dynamics.

Future Research Needs

It has been argued elsewhere (des Clers 1998b) that, over the first ten years of controlled effort regime, the Falkland Islands *L. gahi* fishery has been managed sustainably. Ten years is a short time, though, in which to accumulate information and knowledge about an annual species such as *L. gahi*. More research is needed to clarify its complex life cycle, and to achieve any degree of predictability. Some directions for future research that are currently being developed are discussed below.

Research on the life cycle and population ecology of *L. gahi* has progressed rapidly since 1987. Two directions have emerged. One, more fundamental, has focused on the essential mechanisms of population dynamics and ecology. Another, more pragmatic, has centered on refining the currently used assessment practices and models. In the first direction, Grist and des Clers (1998) have proposed a new model to link seasonal growth and life-cycle duration. The model, although still preliminary, gives a first hope of predictability, because it predicts the size of a squid entering the fishery as a function of seawater temperature six months previously. It also shows that life-cycle duration of a cohort (or brood) is likely to depend on seawater temperature and, by analogy with many insect populations, may result in one or two cohorts emerging per year. This, combined with Nolan et al.'s (in press) suggestion that the two fishing areas support two reasonably distinct populations, would reconcile the research suggesting three broods (Hatfield and Rodhouse 1994b; Hatfield 1996). At the same time it could explain Agnew et al.'s (1998, in press) suggestions of two broods from research based on an analysis of the two fishing areas and both sexes combined together.

Many crucial aspects of the biology, ecology, and dynamics of *L. gahi* remain unknown. Multiple broods, extended spawning periods, and separate migrations of the two sexes combine to produce a complex picture during the two fishing seasons and between contiguous areas of the Loligo box. The oceanography of the region is little studied, and its effects (e.g., on the biology of *L. gahi* in the spawning grounds around the Falkland Islands) or its importance to recruitment, growth, and maturation of the species have not been studied. The first six months of the life cycle are almost unknown in relation to geographical distribution, growth, or trophic interactions. The role of *L. gahi* within the Patagonian Shelf ecosystem is little studied, and there is little knowledge about population regulation from within (cannibalism); from other species (predation, competition, food limitation); or from the fishery itself (see Murphy et al. 1994; Brodziak and Macy 1996).

Information collected regularly on the distribution of *L. gahi* off-season and outside the Loligo box is likely to yield important understanding of the population biology of this commercially valuable species. Paralarvae could be surveyed, as they are in Japan to predict adult stock size of *Todarodes pacificus* (Okutani and Watanabe 1983). The paralarval distribution of *L. gahi* in the vicinity of the Falkland Islands is only sketchily known, and an efficient method of capture remains to be identified (see McGowan 1954; Clarke 1977; Recksiek and Kashiwada 1979; Vecchione 1981).

On the more pragmatic side, assessment models could be extended along the lines proposed by Agnew et al. (1998), and notably through a statistical rather than a deterministic approach.

From the point of view of the fisheries manager, estimates of seasonal abundance should be obtained independently from the commercial fishery. Independent survey estimates may be the only potential safeguard against errors such as those which plagued the northern cod assessments (Walters and Maguire 1996). Areal expansion methods, for example, have been employed to determine pre-recruit biomass of exploited loliginid species other than *L. gahi* (Augustyn et al. 1992, 1993; NEFSC 1996).

Finally, a variety of aspects will have to be researched in the near future. Among these are the effort dimension of the fishery; optimal fleet size and technological upgrade; economics of vessel operations; and development of fishing gear, product quality standards, new products, and new and existing squid markets.

Future directions of the fisheries policy should also be designed and evaluated. Changes may arise as more Falkland Islanders assume ownership of fishing vessels, or as a result of the universal trend of privatizing fisheries access rights. Some of this research, and some of the biological research, may be funded entirely by, or in collaboration with, vessel owners. In all cases, the FIGFD is likely to play an important steering role.

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