

**Summary report Northern shortfin squid (*Illex Illecebrosus*) population ecology & the fishery Summit, November 25-26, 2019
Wakefield, Rhode Island**



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Hosted by the North East US Northern Shortfin Squid Fishery represented by Seafreeze Ltd., Lund's Fisheries, The Town Dock, F/V Jason and Danielle, F/V Retriever, F/V Dyrsten, F/V Prevail, F/V Darana R.

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Updated Tuesday, March 24, 2020

Changes: Lines 55-66, 552-566. 3/5/20 corrected miscommunication about SSC OFL process. 3/24/2020. Corrected several unforced errors

5 **1. Executive summary**

This report summarizes information about Northern Shortfin squid (*Illex Illecebrosus*) population ecology & the fishery discussed at a two-day summit hosted by the fishery in Rhode Island, November 25-26, 2019. Additional information is included to provide background and context. The goal of the summit was to develop a framework for collaborative research products that could be produced in the near term (6 months to 1 year) to reduce scientific uncertainties preventing responsive fishery management. ***Since 2017 landings of shortfin squid have been higher than 20 year median values and increasing throughout the Northwest Atlantic from Cape Hatteras, North Carolina to the Flemish cap off Newfoundland, Canada. (Table 3). During the same period indices of squid abundance in fishery independent bottom trawl surveys on the continental shelf have also been generally high and increasing across the same broad geographic region (Table 2).*** Participants in the fishery believe that uncertainties in stock status have produced inflexible fisheries management and early US fishing season closures in the face of the persistent and increasing availability of the squid.

20 The industry developed a two-day agenda (***Appendix table 1***) to review:

- The recent history of population assessment (***section 3***)
- Current understanding of shortfin squid population ecology (***section 4***)
- Recent changes in New West Atlantic ocean dynamics that could affect the availability and productivity of the squid (***section 5***).
- The technical aspects of fishing, and impacts of human dimensions (markets, processing, plant capacities, regulations) on fishing effort and catch, as well as fishery observations of squid ecology (***section 6***).
- Fishery independent and dependent data available, including assets of and data generated by the NOAA/NEFSC Cooperative Research Branch Study Fleet (***section 7***),
- The group then identified collaborative science products that could be developed to inform adaptive fishery management (***section 8***). The processes and deadlines required for products to be reviewed by the May 2020 meeting of the Mid Atlantic Fisheries Management Council's Scientific and Statistical Committee when specifications are developed for the fishery were also identified.

40 The review of assessment and management (***section 3***) indicated that quotas for northern shortfin squid have been set between 19,000 and 24,825 metric tons (mt) since the passage of MAFMC amendment 8 in 1998 which brought the overfishing definition into compliance with the 1996 Sustainable Fisheries Act. Quantitative fishery reference points defining quotas were based on a 1995 stock assessment that used US fishery landings in a surplus production model to estimate a maximum sustainable yield (MSY) of 24,000 mt (NEFSC, 1996a). Numerous flaws were identified in the model including substantial
45 imprecision in parameter estimates. Fishery catchability (q) was the crucial parameter used to scale fishery landings to annual stock biomass and fishing mortality. Since the

calculations were made using US Fishery data alone, *the fishery reference points were based on the assumption that 100% of the shortfin squid population was available to the US fishery. This assumption was not valid* because the US fishery occurs only on the outer edge of the southern New England-Mid Atlantic bight continental shelf during the summer, while late stage juvenile and mature squid use habitats in the slope sea and outer continental from south of Cape Hatteras to Labrador as well inner shelf habitats north of Cape Cod during the summer.

Since stock assessments have not passed Center of Independent Expert review, the MAFMC SSC, with the assistance of MAFMC staff has developed alternative approaches for determining ABC. The SSC relied on observations of the fall NEFSC bottom trawl survey and fishery landings following years when fishery landings were in the 24,000 MT-26,000 MT range to determine that an ABC of 26,000 MT is unlikely to cause overfishing. The MAFMC's risk policy states that ABCs for stocks without an OFL may not be increased by the SSC unless the SSC determines that overfishing is unlikely to occur.

The MAFMC SSC has determined that the northern Shortfin Squid Stock has been lightly exploited because of the relatively small portion of its range within which the commercial fishery operates, justifying setting ABC near the historical maximum catch. The results and assumptions of 1995 assessment, including the flawed availability assumption, are still implicit in the current quota specification process. Quotas based on the 1995 assessment likely limited landings substantially in 1998 and 2004, thus affecting the time series used to set the current 26,000 MT ABC. Never the less, concern about the possibility of recruitment overfishing persists for the squid that has a sub-annual life cycle, no age class storage, and a population ecology that is uncertain.

Discussions about the habitat and population ecology of northern shortfin squid were reviewed at the summit and additional background is added here (*section 4*). Many aspects of the population and habitat ecology of the squid are uncertain because most field data have been collected in summer fisheries and summer and fall fishery independent surveys of US and Canadian continental shelf waters that use bottom trawls to capture large juveniles and adult stages. *Critical habitats for the pelagic squid occur in the shelf slope sea and have been poorly sampled or not sampled at all.*

Shortfin squid is pelagic in all life stages and use convergences associated with the western wall of the Gulf Stream and the slope sea as spawning, larval and early juvenile nursery habitats. Some later stage juveniles and adults appear to remain in the shelf slope sea while others move to the outer continental shelf to feed, as well as to the inner continental shelf north of Cape Cod during the summer. *During the spring and summer from Cape Hatteras to the Newfoundland, cohorts of juvenile and adult squid appear to move from the slope sea onto the continental shelf and off again in broad waves and not through a few chokepoints on the continental shelf where they would be vulnerable to aggregating predators including humans.*

95 *The squid has a remarkable sub-annual, opportunistic life cycle that provides it with*
reproductive resilience in an environment in which resources defining habitat quality
and carrying capacity are controlled by dynamic, ephemeral, and often unpredictable
100 *mixing processes of the western Atlantic boundary current system (Table 1).* Key traits
include a fast protein-based, temperature and body size dependent metabolism with
cannibalism in all life stages; a sub-annual life cycle with multi-batch spawning of
individuals and cohort spawning in multiple seasons or continuously. Multiple spawning
105 areas are possible and seasonal cohorts appear to exhibit asynchronous dynamics. Habitat
use patterns diversify as the squid age to include slope sea, outer shelf and inner shelf
habitats. Finally, development rates of the squid are temperature dependent and more so
than growth rates. Diversity in the timing and locations of spawning, asynchronous
110 cohort dynamics, and adult habitat diversity spread and thus reduce the risk of
recruitment failure across multiple seasonal cohorts and habitats. In addition to these
portfolio effects, cannibalism contributes reproductive resilience in ever changing ocean
conditions. The squid do not store fat for the future but mobilize all metabolic resources
“now” toward performance including reproduction. When they exceed local habitat
115 carrying capacities, large, higher performing squid are believed to cannibalize smaller,
lower performing squid. Cannibalism could permit the best performing individuals to
survive and reproduce when environmental conditions are stressful and result in rapid,
within cohort selection of traits advantageous under diverse and ever changing
environmental conditions. Finally, as waters warm toward a threshold, differences in
120 temperature sensitivities of development and growth result in the earlier onset of maturity
at smaller body sizes. While the fecundity is generally lower at smaller sizes, early
maturation reduces generation time and increases intrinsic population growth rate and
population productivity when environmental conditions become favorable. *The life*
history traits shortfin squid probably confers population resilience when environmental
conditions are stressful and leads to population outbreaks when conditions turn
favorable.

125 Many northern shortfin squid life history processes are controlled by oceanographic
properties and processes associated with the Gulf Stream, slope sea and continental shelf
system. As a result, recent changes in ocean processes, properties, and ocean-
atmospheric interactions that could affect the availability and/or productivity of northern
Shortfin Squid in the Northwest Atlantic were discussed at the summit (*section 5*).
130 Recent observations indicate that *since 2000, amplitudes of Gulf Stream meanders, now*
forming farther to the southwest, have increased and the number of warm core rings
pinching off meanders has nearly doubled. As a result, mixed layer temperatures in
slope sea have increased and more warm core rings are impinging on the southern
New England and the mid-Atlantic Bight outer continental shelf. Eddy-shelfbreak
interactions are causing intrusions of warm slope sea and Gulf Stream water onto the
shelf on the surface as well as the bottom. The intrusions have contributed to the
warming of continental shelf waters including the development of shelf heat waves in
2012 and 2017-18. Ocean mixing processes underlying productivity in the shelf slope
135 *sea and outer edge of the shelf have also been affected.* The observed changes in ocean
dynamics have been associated with changes in the atmospheric pressure gradients in the

North Atlantic and the jet stream, which have in turn, appear to be related to recent warming in the Arctic.

140 Changes observed in the Gulf Stream-Slope Sea-Shelf system could increase the
availability of shortfin squid to bottom trawl fisheries and fishery independent surveys
through two mechanisms that are not mutually exclusive. First, if the warm core Gulf
Stream rings provide efficient migration pathways from the shelf slope sea to the shelf for
145 juvenile and adult squid, then increases in the frequency of warm core rings could result
in the immigration of a larger proportion of juvenile and adult squid onto the continental
shelf. Fisherman report that opportunities for fishing in the early summer are sometimes
anticipated by warm core rings with trajectories that near the continental shelf (*section 6*;
Fig. 7). Second, the observed changes in ocean dynamics could enhance nursery habitat
150 suitability, early survivorship and recruitment and thus population productivity. High
concentrations of larval squid occur in convergences associated with meanders and Gulf
Stream rings (*See section 4*). Upwelling occurs in Gulf Stream meander crests and
decaying warm core rings. Enhanced primary and secondary productivity becomes
concentrated on downstream convergences on the “backs” of wavelike meanders and
155 outer edges of warm core rings where high concentrations squid larvae have been
observed. Young squid associated with warm core rings translating southwest against the
northeastward flow of the Gulf Stream are also likely to be retained within the southern
slope sea gyre. Increases in the amplitude of Gulf Stream meanders and frequencies of
warm core rings may have increased squid nursery habitat suitability by increasing
160 retention in the southern slope sea gyre, as well as habitat carrying capacity, fueling rapid
development and growth and reducing the incidence of intra-cohort cannibalism. Up to a
threshold, exposure to the warming waters of the slope sea and continental shelf could
also increase rates of development, reduce generation times and increase intrinsic
population growth rate and productivity.

165 *Shelf wide increases in both fishery landings and fishery independent survey
abundance indices (Table 1 and 2) in US and Canadian waters suggest that northern
shortfin squid population productivity has increased. If the changes in squid
availability observed are related to only distribution shifts, abundance variations would
be expected to be more localized, matching scales of mesoscale (100 km=54nm)
170 oceanographic features including Gulf Stream rings and streamers.*

Discussions of human dimensions of the northern shortfin squid fishery and fishery
observations of species behavioral ecology are described in *section 6*. The discussion
included review of a harvester survey designed to identify factors determining fishing
175 effort and perceptions of stock condition (*Appendix 6*). Northern shortfin squid is a highly
perishable seafood product caught during the summer on the outer shelf that sells for
relatively low prices and must therefore be caught cleanly in large volumes and processed
quickly. *Effort in the fishery that operates at small profit margins is complex and
controlled by market prices, methods of processing, costs of fishing and processing, as
180 well as the availability of the squid.* Prices for the squid are determined by southeast
Atlantic and western Pacific squid supplies that have contracted in recent years. Domestic
and international calamari markets have expanded for the squid. This has also contributed

to recent price increases. Since 1999 and the end of international squid fishing in Canadian waters, the US fishery has accounted for 97% of squid landings in the Northwest Atlantic. Despite recent increases in the availability of the squid, the Canadian fishery has remained small and artisanal due to limited shoreside processing capacity in Newfoundland and economic opportunity costs. The US fishery is prosecuted with bottom trawls with coarse meshes (3 meters) in net mouths. The nets are designed to maximize herding of the squid while simultaneously minimizing bycatch that is costly in processing and devalues the product. ***The fishery is extremely clean.*** Four methods of preserving and processing squid, that involve freezing and processing either at sea or shoreside, result in a diversity of fishing practices that make effort standardization with the goal of developing indices of shortfin squid population condition based on fishery landings extremely difficult. ***Fishing is also controlled by quota restrictions for squid and other stocks, including spatial management regulations that prohibit shortfin squid fishing in large areas of the shelf slope sea, outer edge of the continental shelf and the Gulf of Maine where the squid are known to occur.***

Industry observations of the ecology of the squid are consistent with the scientific literature but provide additional insights because fisherman sample continuously at finer spatial scales. Bottom trawl fishing (net heights < 18M) occurs mainly during daylight hours when they squid are near the seabed. There is constant immigration of squid from the slope sea to the shelfbreak as well as along shelf movements. The squid aggregate in large dynamic shoals that appear and disappear quickly. The availability of squid is sometimes anticipated by warm Gulf Stream core rings that come near to the outer edge of the shelf, but fisherman view the animals to be largely unpredictable. Fisherman observe the squid year round on the shelfbreak, find evidence of spawning year round, and longliners have observed large squid in the slope sea and on both the north and south sides of the Gulf Stream. As good fishing seasons progress, body sizes of squid are large and seem to increase along with catch per effort.

Following discussion of available data and infrastructure, including assets of the NOAA/Northeast Fisheries Science Center, Cooperative Research Program and its study fleet (*Section 7*), the summit participants discussed collaborative industry science initiatives that could be developed to reduce uncertainties in stock status and result in greater flexibility in fishery management (*Section 8*). These included long term (2-5 yrs) and medium term (1-3 yrs) information rich investigations of linkages between a) stock availability, productivity and ocean dynamics, b) collaborative real-time monitoring of fishing and processing operations developed with the NEFSC Cooperative Research Program, c) and the development of indicators for in-season quota adjustment using an industry-science collaborative survey of the outer continental shelf conducted when landings reach certain percentages of allocated quotas.

The group then focused on developing a product that could be completed in the near term (6 months) to inform the MAFMC SSC decisions about the Acceptable Biological Catch (ABC) Control Rule in the late spring of 2020 (*Section 8*). Proposed was ***a method to estimate of the proportion of the known geographic range of Shortfin Squid accessed by the US fishery each year as a means to estimate availability to the fishery, a***

230 *maximum bound to fishing mortality and its complement, the proportional area squid*
occupies that allows for escapement from the fishery. This product was designed to
address the flawed assumption implicit since 1998 in the scientific foundation of
harvest policy; that %100 of the northern Shortfin Squid Stock is available to the US
fishery. The group was advised to adopt a conservative approach by confining the
235 analysis to fishery and fishery independent survey data collected with bottom trawls in
US continental shelf waters where the fishery is well monitored and surveys are routinely
conducted. Analysis of areas occupied (A_o) by the squid should not include data from
Canadian surveys and any information available for the shelf slope sea. Further the
group was advised to develop estimates of the area fished (A_f) by the US fleet using the
240 standard method for mapping the distribution landings for bottom trawl trips greater than
4.5 mt (10,000 lbs) by ten-minutes squares ($\sim 10 \times 10$ nm). Fishing operations occur at
smaller horizontal length scales (*see section 6*). This approach should yield conservative
estimates of availability to the fishery ($\rho = A_o/A_f$) and F_{max} will be higher than the true
values while estimates of proportional escapement ($1-\rho$) of fish from the fishery will be
245 lower than the true state of nature. Additional, supporting indicators of stock condition
were also discussed. Finally the process and deadlines required for product review and
consideration by the MAFMC SSC and MAFMC council were identified.

Introduction

250 The US northern shortfin squid (*Illex illecebrosus*) fishery invited 34 participants
(*Appendix 1*) to the summit. The industry developed a two-day agenda (*Appendix 2*),
providing a review of material required to understand key issues related to the scientific
assessment of the squid population and fishery, and the time to outline collaborative
255 research products. The design of the summit reflected the industry's belief that
developing the scientific information necessary for rational, responsive fishery
management requires strong collaboration between the fishing industry and the fishery
science and management communities. The industry invited science, policy and industry
experts with a diversity of perspectives for an honest, open, productive review of the state
of the science and the fishery and to develop frameworks to address scientific
260 uncertainties. The goal was to outline science products that could impact science and
management system in the near term; ideally in time for the 2020 fishing season.

2.1 Method

This document was constructed in the following manner. A draft of the report was
developed from materials presented at the summit, a synthesis of notes from several
265 participants in the summit, and an audio recording of the proceedings. This information
was supplemented with background information from the scientific literature and the
fishery. A draft of the report was circulated to several participants for review and
comment. Comments were incorporated into the final draft to ensure that this document
accurately captures issues discussed at summit. The following is a detailed summary of
270 information shared during summit along with relevant background information.

3) Current scientific basis of shortfin squid management & review of earlier industry science collaborations

275 This session was lead by Paul Rago who provided a general review of the theory of stock
assessment and the assessment and policymaking processes before leading the discussion
about the specifics of shortfin squid assessment and management.

3.1 Definitions relevant to the discussion

280 *Depletion method:* Method for estimating the initial size of a population size by
monitoring changes in abundance as the fishery removes fish. Other vital rates of
populations can be measured using depletion methods if changes in abundance associated
with recruitment, immigration, emigration, natural mortality, and fishing mortality can be
teased apart.

285 *Escapement:* Estimate of the number of spawners surviving the fishing season and thus
available to spawn new recruits.

Exploitation index: The ratio of landings divided by a fishery independent CPUE index in
numbers or biomass. Often rescaled using a multiplier to the scale of mortality.
290 Exploitation indices are assumed to the proportion of the total population, indexed by
fishery independent CPUE, removed by fishing as indexed by landings.

295 *Maximum spawning potential (MSP)*: An estimate of the amount of spawning stock
biomass produced per unit biomass of recruits (SSB/R) when fishing mortality (F) is
zero. A fishing mortality reference point (F) can be set as a percentage of MSP . F
20%MSP would be a fishing level at which 20% of maximum spawning potential would
occur.

300 *Recruitment overfishing*: Fishing that causes enough mortality of mature adult spawners
that the population cannot replenish itself with new recruits.

Semelparous: Organism that has only one reproductive episode before dying.

305 *Stationarity*: assumption that a characteristic or process changes randomly without a
significant trend in space or time.

Stock Recruitment Relationship (S/R): Relationship of the number or biomass of
spawning adults to the number or biomass of new recruits the spawners produce.

310 **3.2 General overview of stock assessment and the assessment and management process**

The objective of stock assessment is to estimate total stock abundance and set biological
limits on fishery harvest rates that ensure viable and sustainable populations for the
benefit of society. Time series data that accurately account for two of three of the terms
of the following catch equation are required for most assessments.

315 $catch = fishing\ mortality \times population\ abundance$

Fishery independent surveys or fishery dependent measures of abundance, such as catch
per unit effort (CPUE), are used to estimate trends (increasing, decreasing, or
320 unchanging) in population size and condition (e.g. growth, age class diversity). Fishery
removals (landings + discards) are typically used to estimate the scale of stock size
(rough estimate of the order of magnitude of the stock). Determining trends and the scale
of a population is difficult when the population is only partially available in space and
time to the fishery and fishery independent surveys. A reasonable understanding of
325 species life history, especially longevity, growth, natural mortality, maturation, and
migration is also required for accurate stock assessment. Using fishery dependent and
fishery independent survey data to determine the nature of the relationship between the
amount and condition of spawners and the amount of new recruits they produce is also an
important and difficult challenge (i.e. stock recruitment relationship). The early life
330 stages (eggs, larvae, early juveniles) of marine fish and invertebrates suffer high natural
mortality rates that vary from year to year usually as a result of changes in the
environment. These early stages are generally poorly sampled or not sampled at all.
Variable mortality in early stages weakens and can eliminate relationships between the
size of the spawning stock and the abundance of recruits they produce (i.e. stock-
335 recruitment relationships).

Assessments require assumptions about processes underlying the population ecology of
fish stocks and human observations of stock characteristics. It is often assumed that some

340 or all of these processes vary randomly without systematic trends. This is the *stationarity*
345 *assumption*. Immigration into and emigration out of stock areas are usually assumed to be
small and stationary and thus stocks are assumed to be “closed”. Human observations of
population trend and scale are assumed to be unaffected by directional changes in the
environment, including human dimensions (economics, regulations, resource conflicts).
When these assumptions hold, observations should reflect the true condition of the fish
population and the fishery.

350 Northern shortfin squid are exceptionally difficult to assess and because many aspects of
the species population ecology are uncertain and many of the fundamental assumptions
made in stock assessments about population ecology and human observations are not
valid.

355 **3.2.2 Stock assessment process:** Most stock assessments in the Northeast US are
performed by working groups of experts led by staff of the Northeast Fisheries Science
Center (NOAA/NEFSC). Since 1998 stock assessments have been formally reviewed by
reviewers from the Center of Independent Experts (CIE;
<http://ciereviews.org/reviewer.php>). The deliberations of assessment working groups and
CIE reviews are open to the public and results are published and archived by the NEFSC.
https://www.nefsc.noaa.gov/saw/reviews_report_options.php. Northern Shortfin Squid
360 have a geographic broad range that crosses national boundaries. The squid are therefore
also assessed by the North West Atlantic Fisheries Organization (NAFO;
<https://www.nafo.int/Science/Science-Advice/Species>). Assessment documents in
NOAA/NEFSC, NAFO and other archives are the world’s greatest source of unread
information about marine fish populations and fisheries.

365 Assessments serve as the basis for the development of fishery management council
fishery management plans (see MAFMC plans
<http://www.mafmc.org/fisheries/fmp/msb>). The shortfin squid fishery in US waters is
managed by the Mid Atlantic Fishery Management Council (MAFMC). The MAFMC
Scientific and Statistical Committee (SSC) develops alternative harvest policies from
370 assessments and other information. Fishery management council members then vote on
the harvest policy alternatives. The MAFMC is made up of 21 voting and four non-voting
members. Thirteen voting member are private citizens, while eight voting members
represent constituent state fish and wildlife agencies and the NOAA NMFS regional
office. Non-voting members represent the Atlantic States Marine Fisheries Commission,
375 the U.S. Fish and Wildlife Service, the U.S. Department of State, and the U.S. Coast
Guard. Mid Atlantic Council and SSC deliberations are also open to the public.

3.3 Scientific basis of Northern shortfin squid fishery management.

380 Background literature including the most recent MAFMC Fishery information document,
MAFMC Fishery Performance Report and the 1995 and 2006 assessments (SAW 21 &
42) were provided to participants before the summit (see *appendix Table 3*). Paul Rago
also provided a summary review of NEFSC led stock assessments for Northern Shortfin
Squid that is included in *appendix Table 4*. Since the establishment Center of
Independent Expert Review, none of the stock assessments of Shortfin Squid have passed

385 review because so many aspects of the species population ecology are unknown,
sampling is incomplete, and the assumptions typically made in assessments about
population ecology and observations do not hold.

390 **3.3.1 Current tensions:** Current tensions in the US Northern shortfin squid fishery
system have been created by a legal mandate arising from the 1996 Sustainable Fisheries
Act requiring the development of quantitative fishery reference points based on long term
average maximum sustainable yield (MSY) for population biomass (B_{MSY}) and fishing
mortality (F_{MSY}), and the absence of much of the biological information required to
compute the reference points. These tensions are exacerbated by fears of recruitment
395 overfishing in squid with sub-annual life cycles, no age class storage and highly variable
recruitment that is largely environmentally controlled. For these species it is nearly
impossible to know until the annual harvest is completed whether recruitment during the
same year has been high or low. Recent increases in the demand for and prices of
shortfin squid in global and domestic markets that have occurred simultaneously with
400 increases in the availability of the squid to the US fishery. These conditions have
increased the pressure on the fishery science and management system.

405 **3.3.1 Early assessments:** Early assessments of the Northern Shortfin Squid Stock relied
on indices of abundance and size of the squid in the fall NOAA/NEFSC Fishery
independent bottom trawl survey and in fishery landings that both occur on the
continental shelf. Before 1998, overfishing was defined by the MAFMC to occur when
the 3 year moving average of the abundance of prerecruits (<10 cm dorsal mantle length)
in the NEFSC survey fell below the first quartile of the time series. The fall NEFSC
survey is typically conducted after the summer fishery stops. This definition used the fall
410 survey abundance of squid prerecruits as an index of potential spawners escaping the
fishery (i.e. escapement index). The index was questioned in many assessments for three
reasons. First the efficiency of the bottom trawl net is assumed to be low for the squid
that are pelagic and exhibit daily vertical migrations. Secondly, squid occupy habitats in
Slope Sea as well as the continental shelf from Cape Hatteras to Labrador. The bottom
415 trawl survey is conducted only on the continental shelf from Cape Hatteras to the
Canadian EEZ. Thirdly, squid associated with the US continental shelf during the
summer actively migrate during the fall to the shelf slope sea out of reach of the survey
with smaller males migrating before larger females (O'Dor and Dawe, 2013). It is
therefore difficult to know whether annual changes in fall survey abundance reflect the
420 survival of squid or changes in the timing of fall migration.

425 **3.3.1 MAFMC Amendment 8 and the 1995 assessment:** In 1998, the Mid Atlantic
Fisheries Management Council passed Amendment 8 to bring the Squid Mackerel
Butterfish Fisheries Management Plan into compliance with the National Standards of the
1996 Sustainable Fisheries Act (SFA). The SFA required overfishing definitions to be
based on quantitative fishery reference points. In *Amendment 8* overfishing for *Illex* was
defined to occur:

430 “when the catch associated with a threshold fishing mortality rate of F_{MSY} is exceeded.
Annual quotas will be specified which correspond to a target fishing mortality rate of

75% of F_{MSY} . Maximum Optimal Yield OY will be specified as the catch associated with a fishing mortality rate of F_{MSY} . In addition, the biomass target is specified to be equal B_{MSY} . The minimum biomass threshold is specified as % B_{MSY} ”

435 The long term average B_{MSY} and F_{MSY} for *Illex* used in Amendment 8 were determined by
the results of the 1995 stock assessment that applied a Schaefer surplus production to
estimate an MSY of 24,274 mt, $F_{MSY(0.75)}$ to be 1.22 year and B_{MSY} to be 39,300t
(NEFSC, 1996b). The minimum biomass threshold of 50% B_{MSY} was 9650t and the
440 fishing mortality target of 75% F_{MSY} was = 0.56 ($F_{MSY}=0.94$ yr). Since 1998, the
Domestic Annual Harvest Quota for the squid has remained between 20,000 and 26,000
metric tons and tied to the output from the 1995 surplus production model.

There have been numerous critiques of the 1995 surplus production model. The model
used landings and effort in the US fishery to estimate intrinsic population biomass growth
445 rate (r), catchability (q , the proportion of total stock biomass taken per unit effort [E]),
and the equilibrium unfished stock biomass (K). Standardized US landings from 1982-
1993 were assumed to be proportional to the biomass of the stock in a manner captured in
an unchanging catchability coefficient (q). The catchability coefficient (q) is supposed to
equal the proportion of fish available at site captured by the fishing gear
450 (detectability=net efficiency) multiplied by the proportion of the area or volume occupied
by the stock that is sampled by the fishery (availability). The q was calculated on a per
fishing effort basis. The model did not explicitly account for the annual life cycle of the
squid, changes in natural mortality with maturity, or immigration into or emigration out
of the fishing area for the highly migratory oceanic, transboundary stock with a range that
455 far exceeds the US fishing area. Annual stock biomass estimates were developed by
dividing US landings by the catchability coefficient (q) developed in the model.
Estimates of annual fishing mortality rates were then calculated by dividing total landings
by the average annual stock biomass. Fishing mortality (F) is therefore equivalent to
catchability q multiplied by Effort E . Using bootstrapping it was shown that parameter
460 estimates from the model were extremely imprecise ($q=1.537*10^{-3}$, $\sigma_q = 0.786 *10^{-3}$;
 $r=2.44$, $\sigma_r=0.56$, $K= 39,793$ $\sigma_K=129,129$). Standard deviations for q and K were nearly as
large or larger than the estimates themselves and some bootstrapped estimates of q 's were
negative.

465 Since the data used in the 1995 surplus production model was limited to just US fisheries
data, the MSY estimate of approximately 24,000 metric tons was calculated based on the
assumption that 100 % of the stock was available to the US fishery which occurs on the
mid Atlantic Bight and southern New England Shelf Break during the summer. However,
northern shortfin squid range from south of Cape Hatteras to Labrador and occupy
470 habitats in the shelf slope sea as well as the continental shelf (See section 3.1). The
assumption that the stock is % 100 available to the fishery is invalid.

It was pointed out at the summit that values of q from the surplus production model
cannot be interpreted explicitly as net efficiency (=detectability) x population availability
475 to the fishery on a per trip basis because the q was derived from landing standardized
with general linear modeling. Nevertheless, because only US landings were included in

the modeling, the fishery reference points were calculated in the model on the basis of the flawed assumption that 100% of the stock was available to the fishery. The results of the 1995 surplus production models were codified in Amendment 8 in the overfishing definition for northern Shortfin squid.

3.3.3 Recent assessments: Since 1998 important efforts have been made to improve the scientific assessment of the northern shortfin squid population through collaborative fishery monitoring and modeling. It was recognized, since the early 1990s, that collaboration with the fishing industry in an in-season assessment and management approach could be most effective because the fishery sustains access to some portion of the short lived squid population (see *Appendix Table 5 & 6*). Efforts to develop in-season assessment and management in the US have been modeled after the real time approach developed for the Argentine shortfin squid fishery in the Falklands. To manage the Falklands fishery, a survey is performed to estimate the abundance of the squid just before the fishery begins (Dunne, 2017). The fishery is then monitored in real time to measure rates of change in fishery CPUE using a depletion modeling approach. Body sizes and ages of squid are also monitored to the degree possible. The fishery is closed when an F target is reached that provides a precautionary minimum bound for the proportion of potential spawners escaping the fishery. Efforts in the US have been patterned after the Falklands approach, particularly with respect to fine temporal and spatial resolution of the fishery data. This sort of data was considered in stock assessments conducted from 1999-2006 (SARCs 29, 37, 42; https://www.nefsc.noaa.gov/saw/reviews_report_options.php).

Attempts to apply real time assessment and depletion methods to the Northern Shortfin squid fishery in the US have been largely unsuccessful. These failures have been attributed to two causes. 1) Fishery dependent catch data has not been collected at a high enough resolution. 2) The fishing area is open to immigration and emigration and receives continuous waves of new and sometimes, indistinct cohorts of squid throughout the season. During some years the squid remain abundant throughout the season and rates of fishery CPUE do not decline over time, but in fact increase during some years. This has occurred since 2017. Inflection points in the CPUE data required to tease apart growth, mortality and movement processes are not detectible. It was pointed out by Paul Rago that “*depletion modeling*” is a bit of a misnomer. The approach can provide insights into population condition and dynamics even if depletion is not observed so long as variations in abundance and body size can be attributed to growth, mortality and movement processes. It should be pointed out that Falklands fishery occurs at the confluence of the Brazil Current and Antarctic Circumpolar Current, a possible “chokepoint” for the Argentine squid (Jullion et al., 2009; Dunne, 2017). This is more similar to the confluence of the Gulf Stream/North Atlantic and Labrador currents off the Grand Banks and the Flemish Cap than southern New England and the mid Atlantic Bight where the animals move continuously between the shelf-slope sea and continental shelf over a broad region.

The 2003 and 2005 assessments (SAW 37 & 42) developed fishery reference points using an elegant age-based cohort model that accounted for the total mortality of spawning

squid combined with an egg per recruit model (Hendrickson and Hart, 2006; NEFSC, 2006). The results were informed by industry-science collaborative research investigating size and age at maturity in the squid, a pre-season survey of abundance and fishery CPUE developed using in season monitoring. This work was applauded by CIE reviewers but the results were ultimately rejected because they were based on limited and uncertain age, growth and maturity data collected in the Southern New England and the Mid Atlantic Bight during the spring of one year (Hendrickson, 2004).

3.3.3 NAFO Assessments and the “productivity” hypothesis: NAFO assessments of northern shortfin squid in US, Canadian and international waters have also influenced thinking about the stock in the US, particularly with respect to the “productivity regime hypothesis” (see <https://www.nafo.int/Portals/0/PDFs/sc/2019/scr19-042.pdf>). The NAFO assessment is developed through collaboration between the scientist currently leading the US assessment and a Canadian stock assessment scientist. The “productivity regime hypothesis” framework, developed by Rivard et al. (1998) does not explicitly link population productivity to population and environmental processes but is based on perceptions of relative abundance of squid in Canadian landings and fishery independent surveys. An F proxy is developed from an exploitation index computed as the ratio of annual fishery landings in Canadian waters to the catch per unit effort of the squid in the July, fishery independent bottom trawl survey of the Nova Scotian Shelf. The Nova Scotian Shelf survey occurs just before the Canadian fishery begins and is assumed to reflect the availability of squid to the fishery. The F proxy is computed by multiplying the exploitation index by 10,000, which puts the F_{proxy} on the characteristic scale of mortality rates. The history of Canadian landings is used to define 2 regimes of fishery yield (“~productivity”). Mean landings for the years 1976-1981 are used to define the high yield period. Foreign fleets with extremely large capacities fished for northern shortfin squid in Canadian waters only during these 5 years. The entire landings time series is averaged to determine the low yield regime. This includes periods when significant reductions in fleet capacity and landings in the northern Stock area occurred as a result of fishery regulations including the establishment of the Canadian EEZ (1995), and a ban on foreign fishing on the Scotia Shelf in 1999. This index should not be interpreted as reflecting the biological productivity of the shortfin squid stock because it is confounded by the history of profound changes in fishing capacity in Canadian waters.

3.3.4 Current approach used by the MAFMC Scientific and Statistical Committee:

Since stock assessments have not passed Center of Independent Expert review, the MAFMC SSC, with the assistance of MAFMC staff has developed alternative approaches for determining ABC. The SSC relied on observations of the fall NEFSC bottom trawl survey and fishery landings following years when fishery landings were in the 24,000 MT-26,000 MT range to determine that an ABC of 26,000 MT is unlikely to cause overfishing. The MAFMC’s risk policy states that ABCs for stocks without an OFL may not be increased by the SSC unless the SSC determines that overfishing is unlikely to occur.

The MAFMC SSC has determined that the northern Shortfin Squid Stock has been lightly exploited because of the relatively small portion of its range within which the commercial

570 fishery operates, justifying setting ABC near the historical maximum catch. The results
 and assumptions of 1995 assessment, including the flawed availability assumption, are
 still implicit in the current quota specification process. Quotas based on the 1995
 assessment likely limited landings substantially in 1998 and 2004, thus affecting the time
 series used to set the current 26,000 MT ABC. Never the less, concern about the
 possibility of recruitment overfishing persists for the squid that has a sub-annual life
 575 cycle, no age class storage, and a population ecology that is uncertain.

Areas closed to *Illex* Fishery that provide “escapement”. includes Mid Atlantic coral zone, lobster GRAs (seasonal), Tilefish GRAs, NE canyons & seamounts (Inset). Include also New England Coral Zones, Regulated Mesh Areas. Directed fishery closed during winter

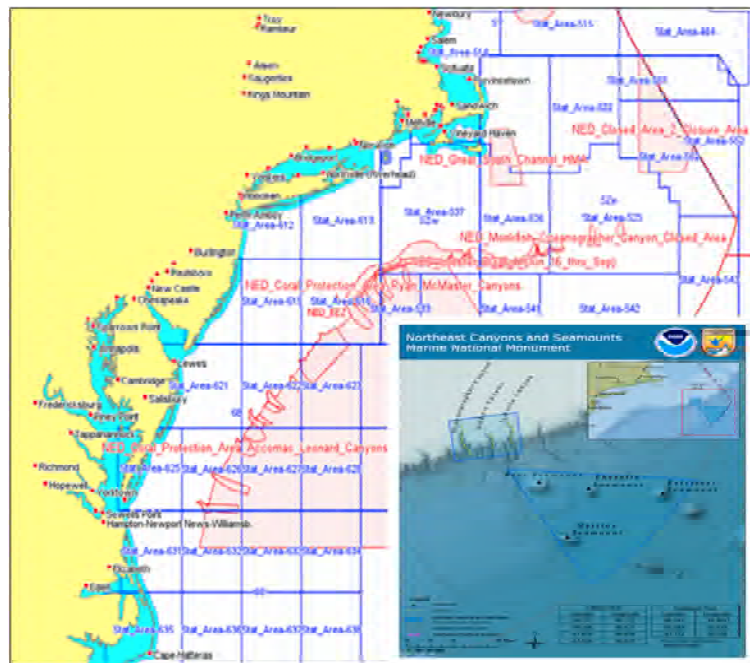


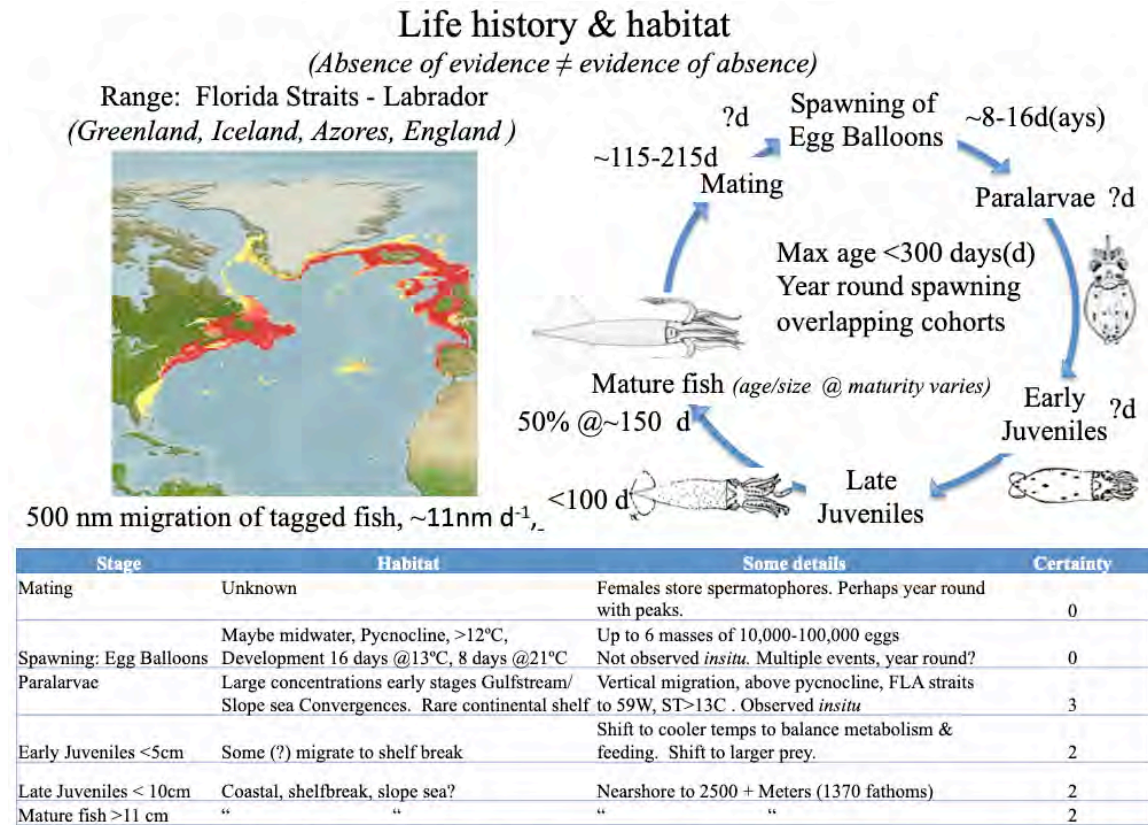
Figure 1. Areas shaded in red are closed to commercial fishing for Northern Shortfin Squid as a result of spatial management measures.

580 **3.3.5 Spatial fishing regulations and escapement:** The focus of science and management
 of the *Illex* fishery has been to ensure that sufficient numbers of mature squid escape the
 fishery to provide for recruitment. Assumptions about the relationship between area
 fished as well as surveyed and the stock area are implicit in all the approaches taken to
 assess the stock and to ensure adequate escapement. The role of spatial management
 regulation in providing “protected areas” for the animals and escapement were therefore
 discussed at the summit.

585 Northern shorfin squid are likely to occupy a number of areas in the shelf slope sea and
 on the continental shelf sea (See section 3.1) that are off limits to commercial fishing as a
 result of spatial management regulations. These areas include the *Frank R. Lautenberg
 Deep-Sea Coral Protection Area*, the *Northeast Canyons and Seamounts National
 Monument*, the tilefish and lobster gear restricted areas, and other regulated mesh areas in
 590 Southern New England and the Mid Atlantic Bight that prohibit the use of fine mesh
 trawls used by the squid fishery. The Coral Protection Area occurs along the shelf break

at depths greater than 450 m (246 fathoms), covers 38,000 square nautical miles including a large area of the slope sea, and 15 canyon areas where the shortfin squid fishery cannot be prosecuted. Large concentrations of the squid have also been collected near seamounts within the 4,913 square mile Monument Area that is now closed to mobile gear fishing (Shea et al., 2017).

4) Review of *Illex* population and habitat ecology



600 Certainty: 0=none, 1=little, 2=some, 3 = pretty sure

Figure 2. Summary of what is known about *Illex illecebrosus* life history and habitat use (see also table 1).

605 Many aspects of northern shortfin squid life history and habitat ecology are uncertain. Our perceptions of the ecology of the squid are shaped by the sampling frames of fishery independent surveys and fisheries mostly conducted with bottom trawls during spring, summer and fall on the continental shelf, as well as a few laboratory studies and studies of related species. Most of the squids geographic and habitat range is not routinely sampled using gear effective for capturing their history stages that are all pelagic.

610 Shortfin squid use the shelf slope sea, western edge of the Gulf Stream and its features as principal spawning and nursery grounds and the continental shelf as an important feeding ground (O'Dor and Dawe, 2013). Physical and biological processes associated with the Gulf Stream and shelf slope sea that are dynamic, unpredictable and ephemeral determine the dispersal, development, growth and ultimately the survival of egg, larval and early

615 juvenile squid. Recruitment is primarily determined in these early life stages. The squids
uniquely opportunistic “live fast and die young” subannual life cycle of overlapping
cohorts, exceptionally fast protein based metabolism, cannibalism, phenotypic plasticity
with variable development and growth, and potentially high production to biomass ratios
620 appears to be finely tuned to the unpredictable dynamics of its liquid habitat template
(sensu Southwood, 1977).

4.1 *Species geographic and habitat range*

The geographic range of northern shortfin squid extends from the Florida Straits
northeast to Labrador, the Flemish cap, Baffin Island and Southern Greenland (Trites,
625 1983; Dawe and Beck, 1985; Jereb and Roper, 2010). There are confirmed reports of the
species farther to the east in Iceland, the Azores and in the Bristol Channel England
(Roper et al., 1998; O'Dor and Dawe, 2013). The eastern extent of the species is dynamic
in a manner suggesting that it is driven by atmospheric variability (Dawe et al., 2000;
Dawe et al., 2007).

630 Based on shelf wide fishery independent bottom trawl surveys and fisheries, adult and
large juvenile squid occur year round near the outer edge of the continental shelf in the
Mid Atlantic Bight (Hendrickson and Holmes, 2004; O'Dor and Dawe, 2013). During
warmer months they are abundant from the outer shelf to the nearshore in the Gulf of
635 Maine and Canadian waters. They can also occur in the nearshore in southern New
England and the mid Atlantic Bight during the spring (unpublished Northeast Area
Monitoring and Assessment Program Survey data, NEAMAP). Larval and early juvenile
squid are rarely collected on the Continental Shelf (see below).

640 The species also occupies shelf slope sea habitats as adults as well as larvae and
juveniles. Bottom and midwater trawl and submersible surveys of the shelf slope sea have
documented high concentrations of juvenile and adult squid to bottom depths of 4800
meters (=2625 fathom) far outside the domains of fishery independent bottom trawl
surveys of the US continental shelf (max depth 95% quantile = 240m = 131 fathoms;
645 *Politis et al., 2014*). Trawl surveys conducted from 169m (=92 fathom) to 4,800 m
(=2625 fathom) in the slope sea off the Nova Scotian Shelf collected *I. illecebrosus* at
depths greater than 500 meters (273 fathom) where the species was nearly twice as
abundant as the second most abundant species (Jereb and Roper, 2010). Mature squid
have also been collected at depths to 1000m in a fall bottom trawl survey of the
650 continental slope from Georges Bank to Cape Canaveral and the species was the most
abundant organism captured in trawls to depths of 2500 meters (1367 fathoms) in the
vicinity of the Bear Seamount in the shelf slope sea (Vecchione M and G.; Rathjen, 1981;
Harrop et al., 2014; Shea et al., 2017). Large concentrations of early and late stage larvae
and juveniles occur only in the shelf slope sea (Hatanaka et al., 1984; Csanady and
655 Hamilton, 1988; Perez, 1995; O'Dor and Dawe, 2013).

All life stages of Shortfin squid are pelagic and spend significant amounts of time in the
water column in the shelf slope sea and on the continental shelf. Submersible as well as
mid-water surveys of the slope sea have observed large concentrations of adult *I.*
660 *illecebrosus* in the water column (Vecchione M and G.; Harrop et al., 2014; Shea et al.,

2017). The squid also spend significant amounts of time in water column on the US and Canadian Continental Shelf (Froerman, 1981; Brodziak and Hendrickson, 1998; Jereb and Roper, 2010b). Larval and early juvenile squid are fully pelagic and caught only in the shelf slope sea mixed layer (=pycnostad; Hatanaka et al., 1984; Perez, 1995; O'Dor and Dawe, 2013)

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The broad geographic range and diversity of habitats used by northern Shortfin squid, much of it outside the range of the fishery and scientific surveys, has never been adequately accounted for in stock assessments and fisheries management.

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4.3 Life cycle: Shortfin squid have evolved an extreme opportunistic life history strategy appropriate for maintaining resilience for a population dependent during early life on the dynamic and unpredictable interfaces of the Gulf Stream, the shelf slope sea pycnostad and the outer edge of the continental shelf. The squid live less than 300 days, have small eggs and high fecundity (Hendrickson, 2004; Jereb and Roper, 2010; O'Dor and Dawe, 2013). The squid spawn multiple batches (=balloons) and spawning occurs across multiple seasons or perhaps continuously. The species produces multiple overlapping cohorts each year.

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Sexes are separate and egg fertilization and spawning do not co-occur with mating. Mating occurs quickly, without elaborate courtship and consists of the transfer by males of spermatophores to the inside of the mantle cavity of females that store the spermatophores. Males and females mate with multiple partners. Males produce approximately 600 to 1800 spermatophores. There is some speculation that reproductive capacity could be limited by shortages of males (O'Dor and Dawe, 2013).

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During spawning, eggs are fertilized with the formation and release of nearly neutrally buoyant egg balloons made of nidamental gland jelly pumped from between the arms of female squid (Jereb and Roper, 2010). In the laboratory females can produce as many as 6 egg masses up to 1 meter in diameter that contain 10,000 to 50,000 eggs. The typical 400g female produces about 200,000 eggs (O'Dor and Dawe, 2013). Total mortality is believed to occur just after spawning because females die just after spawning in the laboratory (Durward et al., 1989). Northern shortfin squid spawning and egg balloons have never been observed in nature.

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Female squid migrate in the fall off the continental shelf into the shelf slope sea and then southward after males migrate. The Blake plateau off the southeast US coast is believed to be an important winter spawning ground. Spawning occurs year round, but peaks in spawning or early stage survivorship occur during the winter, spring, and summer (Perez and O'Dor, 1998; Perez, 1995). Winter spawned cohorts support summer fisheries and are collected in the US and Canadian fishery independent bottom trawl surveys of the shelf. During some summers the US fishery is supported by two cohorts while the Canadian fishery appear to be supported by a single cohort. Winter fisheries operating on the Mid Atlantic and Southern New England shelf break also collect short fin squid that can be "*abundant but often smaller in size*". Presumably these squid are products of spawning events in the summer and fall. According to fisherman, the availability of

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squid incidentally caught during winter fishery does not forecast availability to the directed fishery during the summer (*section 6*). This suggests that the dynamics of seasonal cohorts is asynchronous which has been observed in other ommastrepid squid (Ogawa and Sasaki, 1988; Nakata, 1993)

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Nearly neutrally buoyant egg balloons are believed to be associated with pycnoclines in the vicinity of the western wall of the Gulf Stream and shelf slope sea, including the base of the slope sea pycnostad, a 200km wide by 1600km long surface water mass extending from approximately the latitude of Maryland to the Grand Banks. The base of the pycnostad is a sharp temperature gradient located at 200 (109 fathoms) to 500 meters (273 fathoms) where surface water greater than 12°C (53.6°F) overlies deeper colder water (~6°C , 42.8°F; Csanady and Hamilton, 1988; Perez and O'Dor, 1998; O'Dor and Dawe, 2013). The development of shortfin squid eggs is temperature dependent. Eggs exposed to 12.5°C or colder water fail to develop. Thus egg balloons presumably do not hatch if they occur beneath the slope sea pycnostad. Eggs exposed to 13°C hatch from balloons in 16 days while it takes 6 days for eggs exposed to 26°C to hatch. Conclusions about spawning and egg habitat are based on the properties of egg balloons, distributions of spent females and larvae, as well as temperature dependent egg development. It is thought that egg balloons could be carried 1000km (540 nm) to the northeast before hatching since the average current speed of the Gulf Stream is ~6 .5 km h⁻¹ (3.5 nm h⁻¹). However, current velocities are lower and directionally complex along the steep vertical and horizontal gradients where egg balloons are most likely to be concentrated (Csanady and Hamilton, 1988; Chen and He, 2015).

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Squid hatch from egg balloons as tiny, 1.1 mm mantle length long rhynchoteuthion paralarvae with tentacles fused into a trunk-like proboscis. The proboscis and associated mucus is believed to be useful for trapping small bacteria and microbes that serve as food for the small open ocean larvae (Cho, 1990; Vidal and Haimovici, 1998). Tentacles separate in 5 mm long (ML) transitional stage larvae that begin to actively feed on small crustaceans, and can presumably be cannibalistic. Larvae reach the juvenile stage at 7-10 mm in mantle length and begin to incorporate fish into their diets.

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Shortfin squid paralarvae occur year round in features associated with the western wall of the Gulf Stream and the shelf slope sea. In the early 1980s, an extensive winter plankton survey of the outer continental shelf, slope sea and western wall of the Gulf Stream from 74°W to 52°W collected over 1000, mostly rhynchoteuthion, larvae at depths less than 200m (Hatanaka et al., 1984; Hatanaka, 1986). The highest concentrations were associated with convergent features of the Gulf Stream west wall and warm core rings where water temperatures ranged from 13°C (55.4°F) to 18°C (64.4°F). These surveys collected few transition stage larvae. Larval squid have been consistently rare in shelfwide plankton surveys of US waters and thus nursery habitat appears to be confined to the slope sea (Rowell et al., 1985; Richardson D., Pers Comm.). Networks of divergent upwelling fronts and convergent fronts downstream associated with Gulf Stream meanders and southwestward translating warm core rings may concentrate primary and secondary productivity and serve as high quality feeding habitats for squid paralarvae. These features and the counter clockwise flow of the southern slope gyre

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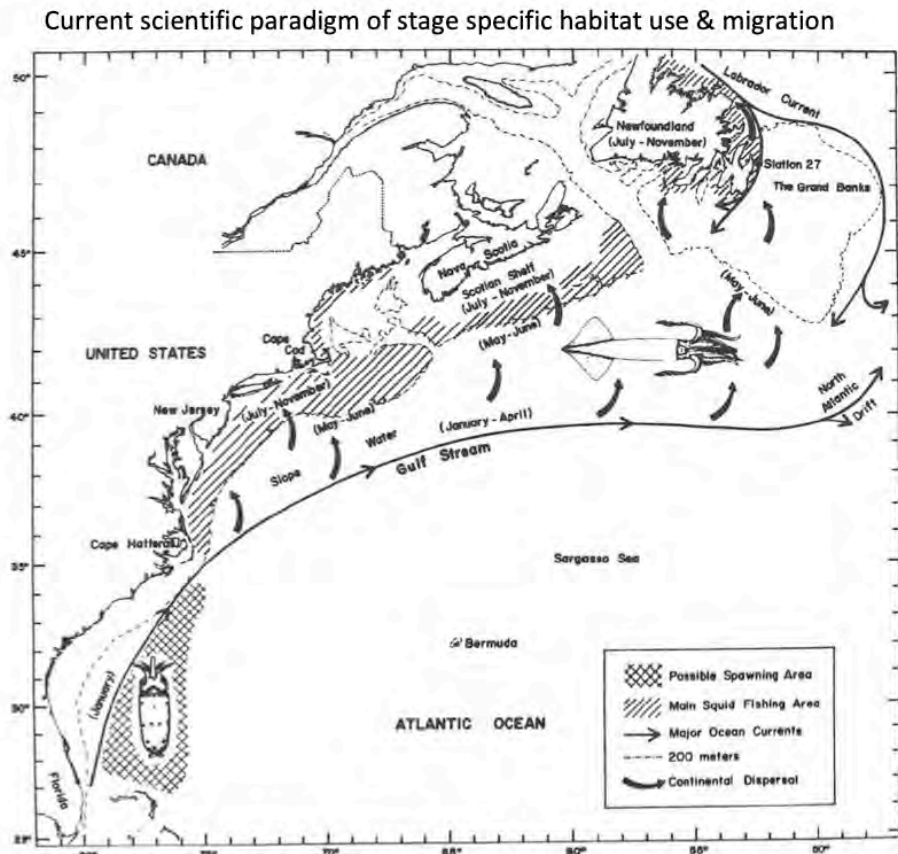
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may be important mechanisms promoting southwestward transport and retention of larvae and early juvenile squid against the northeastward flow of the Gulf Stream (Bakun and
755 Csirke, 1998; Csanady and Hamilton, 1988; Chen and He, 2015)

Early juvenile squid are believed to migrate from the shelf slope sea to the continental shelf seeking cooler temperatures and higher concentrations of larger sized prey. This
760 shift in habitat with increasing size is believed to allow the squid to sustain temperature dependent feeding rates required to meet temperature dependent metabolic demand that increases with body size (Perez, 1995; Perez and O’Dor, 1998).

Adult distributions are already described in *section 3.1*



765 **Figure 3. Generally accepted paradigm of stage specific habitat use and seasonal migration in northern shortfin squid.**

4.4 Movements and migration: The current paradigm of northern shortfin squid migration (*Fig. 3*) is largely based on observations made in US and Canadian bottom
770 trawl fisheries, seasonal fishery independent bottom trawl surveys of the continental shelf and a few other sources. Winter spawned cohorts dominate these collections. Migration of shortfin squid is likely to be more complex and perhaps include a diversity of seasonal/spatial circuits (*sensu* Secor, 2002). The diversity of adult habitat use and multiplicity of annual cohorts lends support to this idea.

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In the spring some proportion of the winter spawn stock migrates inshore from the slope sea to occupy summer feeding habitats on the continental shelf from the mid Atlantic Bight to Newfoundland. In the fall, squid using shelf habitats migrate into the slope sea and presumably to the south where they overwinter and spawn. Males migrate offshore before females (O'Dor and Dawe, 2013). The animals can perform long distance seasonal migrations in the Northwest Atlantic. Squid tagged during the summer off Newfoundland were recovered 1000 km (540 nm) to the southwest in the fall, offshore of the Maryland coast. The speed of migration was approximately 20 km day⁻¹ (11 nm day⁻¹).

Squid appear to migrate in waves onto and off of the shelf in the US and Canada at similar stages of maturity and sizes during approximately the same time period. This conclusion is based upon analyses of spatial patterns of squid maturity in US and Canadian fishery independent surveys of the shelf and sizes of squid caught in fisheries (NEFSC, 1999, pg. 246). During migration the squid do not appear to pass through one, or a few chokepoints on the continental shelf. The wavelike migration pattern makes the squid far less vulnerable to predators, including humans, than would be the case if the animals moved through a few chokepoints on the continental shelf.

All life stages of shortfin squid migrate vertically in the water on day-night cycles. Juvenile and adult squid concentrate near bottom during the daytime and disperse into the water column at night (Brodziak and Hendrickson, 1998; Jereb and Roper, 2010; O'Dor and Dawe, 2013. also *see section 6*). Larvae are distributed throughout the upper mixed layer of the water column at night but settle to the base of the mixed layer during the day (Hatanaka et al., 1984).

4.3 Development and growth: Shortfin squid have exceptionally high metabolic rates when compared with other cold blooded organisms, including other squid. Their metabolic rates approach those of warm blooded mammals (Seibel, 2007; Seibel and Deutsch, 2019). Oxygen consumption rates of resting shortfin squid are nearly double that of longfin squid which also have exceptionally high metabolic demand for oxygen (Pörtner, 1997). At 13°C, a 100 gram resting squid also requires 145 calories per hour for routine metabolic maintenance while an active animal requires 582 calories per hour (DeMont and O'Dor, 1984). Fast metabolism requires sufficient supplies of oxygen and appropriate sized prey.

All physiological and behavioral processes depend on metabolism including development and growth. Like metabolism, these processes vary with environmental temperature, as well as body mass in cold blooded organisms like shortfin squid. The effects of temperature on metabolic rates translate differently to biological processes at higher levels of ecological organization (e.g. cellular activity rates, whole individual growth and activity rate, population growth rates). Differences in the temperature sensitivities of shortfin squid metabolic and feeding rates appear to underlie changes in thermal habitat preferences of growing squid (Perez and O'Dor, 1998). Differences in the temperature sensitivities of development and tissue growth in cold blooded invertebrates have consequences for net reproductive rates (R_0) and intrinsic growth rates (r) at the

population level. When sufficient supplies of oxygen and food are available, cold blooded organisms exposed to warmer temperatures exhibit development rates that increase faster than growth rates (Angilletta Jr, 2009). Animals exposed to warmer temperatures therefore move through and complete life history events faster at younger ages. They grow faster too, but not at the same pace as they development. As a result, the animals achieve life stages including sexual maturity at younger ages, but also smaller body sizes. Individual fecundity and net reproductive rate (R_0) can decline because individual females maturing at smaller body sizes generally produce fewer offspring. However, earlier onset of maturity and decreasing generation time are not accounted for in net reproductive rates (R_0). Early maturity and reductions in generation time cause intrinsic population growth rates (r) to accelerate which can have profound effects on population dynamics and productivity (Turchin, 2003; Kingsolver and Huey, 2008; Angilletta Jr, 2009). Reductions in generation time due to temperature effects on development may be an important cause of insect population outbreaks (Regniere et al., 2012; Régnière et al., 2012).

Northern shortfin squid have not been maintained alive in the laboratory for long enough to measure temperature dependent growth and development. However laboratory experiments have been performed with a related ommastrepid species (Japanese flying squid, *Todarodes pacificus*) (Takahara et al., 2017). Remarkably, juvenile *Todarodes* reared at a temperature of 17°C reached maturity in half the time (20 days) of squid raised at 13°C (40 days). Squid raised at 17°C reached maturity at smaller body sizes.

Latitudinal and seasonal differences in age, body size and maturity of shortfin squid in US and Canadian waters are consistent with the consequences of differences in temperature sensitivities of development and growth in cold blooded invertebrates described above (Dawe and Beck, 1997; Hendrickson, 2004; O'Dor and Dawe, 2013). Squid occupying cooler Canadian waters are generally larger in body size and mature at older ages than squid occupying the Mid Atlantic region which mature at younger ages and smaller body sizes. As the summer progresses more of the squid moving onto the outer edge of the continental shelf are mature at similar ages and sizes as squid immigrating inshore earlier in the season when the water is cooler. The decreasing trend in weights of squid in annual fall fishery independent bottom trawl surveys of the US continental shelf may be related to warming slope and shelf water temperatures (Forsyth et al., 2015; Hendrickson and Showell, 2019. *See section 5*). A similar trend in body size is not observed for squid collected on the Nova Scotian Shelf in July where and when waters are colder (Hendrickson and Showell, 2019).

Because growth and development are temperature as well as sex dependent, body size is a poor indicator of age and maturity in northern shorfin squid. Body size is also a poor indicator because of the constant immigration of waves of new cohorts from the slope sea into shelf fisheries and survey areas during the summer, as well as the appearance of positive growth when smaller, weaker squid are cannibalized by larger squid in habitats with insufficient prey resources. Weight at length does appear to be a useful measure of condition for energetic studies, as weight at length increases for squid feeding on higher quality fish prey (O'Dor and Dawe, 2013).

870 As described above northern shortfin squid require large quantities of appropriate size
prey to fuel rapid metabolism, development and growth. Metabolism is protein based and
the squid do not store fat reserves. Instead the squid rapidly convert prey into nitrogen
based products supporting muscle and reproductive tissue development. Larvae and early
juvenile squid consume over 50% of their body weight per day to grow 15-20% and 3-
12% per day respectively. Adult squid at 15°C (59°F) consume 10% of their body weight
875 per day to grow ~ 5% per day. Growth appears to stop in mature squid that allocate
resources to reproduction. Males are 5-10% smaller than females because growth slows
first for males.

880 **4.4. Trophic ecology:** Northern shortfin squid are ferocious predators of prey including
conspecifics. They serve as important prey for many larger predators. Because the squid
have such a broad geographic range, diverse pattern of habitat use and play a central role
in food webs, they are considered important “biological pumps” transferring biomass and
nutrients across many subtropical to subarctic slope sea and continental shelf ecosystems.

885 **4.4.1 Prey**

Shortfin squid require larger size prey as they grow and surf prey-size biomass spectra
available in the life stage specific habitats they occupy (Sprules and Barth, 2015). Tiny 1
mm ryoteuthion larvae probably feed on prey in microbial communities in open ocean
habitats (Cho, 1990; Vidal and Haimovici, 1998). Transition stage larval squid develop
890 tentacles and become predators of crustaceans and other zooplankton. Larger squid
continue to feed on crustaceans but also incorporate fish and squid into their diets. Many
of these larger prey are abundant on the other edge of the continental shelf, but habitats in
the shelf slope sea clearly also have resources required to support the squid as juveniles
and adults (Pitcher et al., 2007; Jereb and Roper, 2010; Shea et al., 2017). On the outer
895 edge of the continental shelf northern shortfin squid feed on euphausiids, myctophid fish
and other fish (Logan and M.E., 2013).

4.5 Predators

900 **4.5.1 Intraspecific predation = cannibalism:** Shortfin squid don't store fat, but still
require resources to support rapid metabolism in an environment in which food
production is controlled by unpredictable, ephemeral ocean processes. As a result, all life
history stages are cannibalistic (O'Dor, 1998b; O'Dor, 1998a). Larger, higher performing
squid eat smaller, poorer performing squid when and where the local population has
exceeded habitat carrying capacity (Ibáñez and Keyl, 2010). Cannibalism supports
905 population resilience in a changing environment through two linked mechanisms. First,
squid in poor condition become a protein source supporting the development, growth and
reproduction of better-conditioned squid in habitats in which the local carrying capacity
is exceeded. Cannibalism is a form of localized density dependent population regulation.
Second, survivors are likely to be better performers. If survivors reproduce, cannibalism
910 is a mechanism for rapid intra-cohort selection of traits with high fitness under local
environmental conditions. Cannibalism allows the squid to adapt quickly to a rapidly
changing, unpredictable, heterogeneous environment.

915 **4.5.2 Interspecific predation:** Northern shortfin squid are an important prey for many
fish and seabirds. On the continental shelf the squid are eaten by silver and red hake,
bluefish, monkfish, fourspot flounder, Atlantic cod, sea raven, spiny dogfish, common
dolphin, pilot whale shearwaters, gannets and fulmars (Hendrickson and Holmes, 2004).
Near the outer edge of the shelf and slope sea they are believed to be an important trophic
link between mesopelagic fish and apex predators including tunas, billfish and sharks.
920 Based on an analysis of stable isotopes, squid occupying the shelf slope have a trophic
position of 4.7, similar to swordfish (5.1) and dolphinfish (4.3; Logan and M.E., 2013).

4.6 Summary of *Illex* traits and possible consequences for population resilience

925 Species life history characteristics, scales of movement, and diversity of habitat use
determine demographic resilience, population productivity, as well as the degree to which
populations are regulated by density-dependence (Winemiller, 2005; Secor, 2015;
Lowerre-Barbieri et al., 2017). Northern shortfin squid have a uniquely opportunistic
strategy that confers population resilience and allows for bursts of productivity in a
dynamic set of ephemeral habitats for which quality is determined unpredictable ocean
930 mixing processes (Table 1). The habitat template used by the squid dictates that it's best
to "*spend it all now because the risks of saving for the future are much too high*". The
species compensates for the lack of traits like age class diversity, that provide population
storage over the longer term, for others that also provide population resilience through
portfolio effects and bet-hedging. These traits include rapid protein-based, temperature
935 and body size dependent metabolism with cannibalism in all life stages; a sub-annual life
cycle with multi-batch spawning of individuals and cohorts spawning continuously or in
multiple seasons. Seasonal cohorts appear to exhibit asynchronous dynamics and
multiple spawning areas are likely. Habitat use patterns become increasingly diverse as
the squid age. Development rates of the squid are temperature dependent and more so
940 than somatic growth rates. Diversity in the timings and locations of spawning,
asynchronous cohort dynamics, and adult habitat diversity probably compensates for the
absence of age class diversity by spreading and minimizing the risk of catastrophic
recruitment failure across multiple seasonal cohorts and habitats. In addition to these
portfolio effects, cannibalism also contributes to reproductive resilience in ever changing
945 ocean conditions. The squid do not store fat for the future but mobilize all metabolic
resources toward performance including reproduction "now". When local habitat carrying
capacities are exceeded, large, higher performing squid cannibalize smaller, lower
performing squid. Cannibalism permits the best performing individuals to survive
stressful environmental conditions and results in rapid, within cohort selection of traits
950 advantageous under diverse sets of ever changing environmental conditions. Finally, as
waters warm towards a threshold, differences in temperature sensitivities of development
and growth result in the earlier onset of maturity at smaller body sizes. While the
fecundity is generally lower for smaller individuals, early maturation reduces generation
times and increases intrinsic population growth rate and population productivity when
955 environmental conditions are favorable. This combination of traits, similar to those of
some insects, promotes population resilience when environmental conditions are stressful
and population outbreaks when conditions are favorable.

4.8. Recent trends in fishery independent abundance indices.

960 Since 2016 yearly indices of abundance of shortfin squid have been higher than 20 year
medians and generally increasing in all fishery independent bottom trawl surveys of the
continental shelf conducted from the Cape Hatteras to the Flemish Cap (*Table 2*). During
the same period fishery landings from US and Canadian waters have also been higher
965 abundance trends developed from bottom trawl surveys and fisheries on continental shelf
because a large portion of the geographic and habitat range of the stock is not sampled.
Further, several recent fishery independent bottom trawl surveys of the US and Canadian
shelf have not been completed. Nevertheless recent trends in fishery independent indices
of abundance and the coastwide increase in landings, suggests that ecological
970 productivity of the northern shortfin population has increased.

Table 1. Ecological traits of northern shortfin squid likely to impact population resilience in ecosystems in which the means production are controlled by ephemeral, and unpredictable oceanographic processes.

Trait	Details	Consequences
Fast protein based Metabolism.	Temperature, oxygen, food and body size dependent. No fat storage for future use	“Eat, drink and be merry for tomorrow you may die”. Don’t save for later. Allocate resources “now” for peak performance including reproduction.
Cannibalism	Within all life stages. Larger higher performers eat smaller poorer performers when local habitat carrying capacity is exceeded	Local density dependence. Rapid intra-cohort selection of high performing phenotypes under stressful, every changing environmental conditions. “Bet hedging” at population level
Development Rate	Fast but plastic as a function of temperature and the availability of oxygen and food	Accelerates under optimal environmental conditions. Earlier maturation, reduction in generation time, increase in intrinsic population growth rate (r) and population productivity
Growth Rate	Fast but plastic as a function of temperature and availability of oxygen and food. Less sensitive to temperature than development.	Achieve life stages including maturation at smaller sizes. Fecundity often depends on body size. Net reproductive rate (R_0) of individuals may decline
Life span	Sub-annual < 300 days	“Eat, drink and be merry for tomorrow you may die”. Don’t delay reproduction and store in age classes when the future is unpredictable..
Spawning	Multiple seasonal cohorts or continuous year round spawning. Multiple batches/egg balloons ~6* 10,000-400,000 eggs.	Spreading the risk over multiple overlapping cohorts within a year. Seasonal cohort dynamics appear asynchronous. Portfolio effects.
Spawning habitats	Defined by slope sea hydrographics and hydrodynamics promoting successful life cycle coupling. Probably multiple spawning areas.	Portfolio effects. Probably spreads risk over space * time
Broad larval Dispersal/retention	Gulf Stream - slope sea continental shelf system from Hattaras to Grand Banks	Portfolio effects. Spreading risk broadly over space*time.
Narrow adult/juvenile	Strait of Florida to Newfoundland and	Portfolio effects. Spreading risk over space*time

migration	probably beyond. Within and between shelf slope sea and continental shelf. Migration circuits are probably diverse	
High juvenile and adult habitat diversity	Slope sea, outer continental shelf, inner shelf where temperatures and available prey promote growth and survival.	Portfolio effects. Spreading the risk over space.

Table 2. Since 2017 Indices of *Illex Illecebrosus* abundance (Mean Kilogram per Tow, Mean Number per Tow) have been trending higher than the 20 year median throughout the Northwest Atlantic based on US, Canadian and EU-Spain/Portugal fishery independent bottom trawls surveys. Fall North East Fisheries Science Center (Fall US NEFSC), Fall southern Gulf of St. Lawrence (Fall Div4t StLau), July Scotian Shelf and Bay of Fundy (July DFO SS), Fall Grand Banks, (3LNO GB), July Flemish Cap . Data from (Hendrickson and Showell, 2019)

Year	Fall US NEFSC	Fall Div4t StLau	July DFO SS	Fall 3LNO GB	July Flemish Cap
2010	0.05, 8.70	0.18, 0.88	1.08, 19.60	0.00, 0.00	43, NA
2011	0.50, 10.00	0.10, 0.86	1.90, 23.00	0.00, 0.00	89, NA
2012	0.05, 6.30	0.12, 0.88	1.50, 16.90	0.03, 0.22	38, NA
2013	0.40, 8.00	0.01, 0.11	0.10, 1.4	0.00, 0.01	0, NA
2014	0.60, 8.30	0.06, 0.28	1.10, 10.10		3, NA
2015	0.50, 9.50	0.00, 0.00	0.20, 2.40	0.01, 0.09	0.001, NA
2016	0.66, 7.60	0.03, 0.39	0.40, 10.90	0.0185, 0.117	3, NA
2017		0.28, 1.35	16.10, 119.90	0.162, 0.907	2359, NA
2018	1.30, 15.80	0.89, 5.07		0.2794, 1.648	49, NA
2019			32.10, 196.00		363, NA
Median: 2000-present	0.60, 8.3	0.10, 0.465	1.5, 16.15	0.03, 0.117	49, NA

975

Table 2. Shortfin squid landings (metric tons, MT) have increased coast-wide in the North West Atlantic since 2017. Med = median of annual landings since 1999 when Canadian stopped licensing foreign fishing. Percent (%) of total landings in NAFO region.

Year	Total Landings	US waters NAFO 5&6		Gulf St Lawrence/ Scotian Shelf NAFO 4		Newfoundland-Flemish Cap NAFO 3		Total Allowable Catch MT	
	MT	MT	%	MT	%	MT	%	CAN (NAFO 3+4)	US (NAFO 5-6)
1999	7693	7388	96	286	4	19	0	75000	19000
2000	9377	9011	96	38	0	328	3	34000	24000
2001	4066	4009	99	34	1	23	1	34000	24000
2002	3010	2750	91	30	1	230	8	34000	24000
2003	7524	6391	85	46	1	1087	14	34000	24000
2004	28671	26097	91	34	0	2540	9	34000	24000
2005	12591	12013	95	30	0	548	4	34000	24000
2006	20924	13943	67	24	0	6957	33	34000	24000
2007	9268	9022	97	16	0	230	2	34000	24000
2008	16434	15900	97	11	0	523	3	34000	24000
2009	19136	18418	96	42	0	676	4	34000	24000
2010	15945	15825	99	18	0	102	1	34000	24000
2011	18935	18797	99	50	0	88	0	34000	23328
2012	11756	11709	100	29	0	18	0	34000	22915
2013	3819	3792	99	27	1	0	0	34000	22915
2014	8788	8767	100	21	0	0	0	34000	22915
2015	2437	2422	99	14	1	0	0	34000	22915
2016	6836	6682	98	18	0	134	2	34000	22915
2017	22881	22516	98	52	0	313	1	34000	22915
2018	25663	24117	94	70	0	1476	6	34000	22915
2019		26922						34000	24825

Med.	10566.5	11709	30	230
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980

Table 3. Since 2016 most landings (metric tons, MT) of northernShortfin squid in Canadian Waters have occurred in Newfoundland and Labrador (NAFO Area 3). Most of these landings made by small vessels less than 34 ft in length. Data from <http://www.nfl.dfo-mpo.gc.ca/NL/Landings-Values>

Year	Canadian Landings NAFO 3 & 4 (MT)	NAFO 3 Landings (MT) Newfoundland	Vessel Lengths (Feet) Landings in MT			
			< 34'	35-64'11"	65'-99'11"	> 100'
2016	152	134	130	None	None	None
2017	364	313	281	32	None	None
2018	1546	1,205	982	223	None	None
2019		2,527	2,179	348	None	None

985 **5) Changes in ocean dynamics possibly influencing movements and productivity of northern shortfin squid**

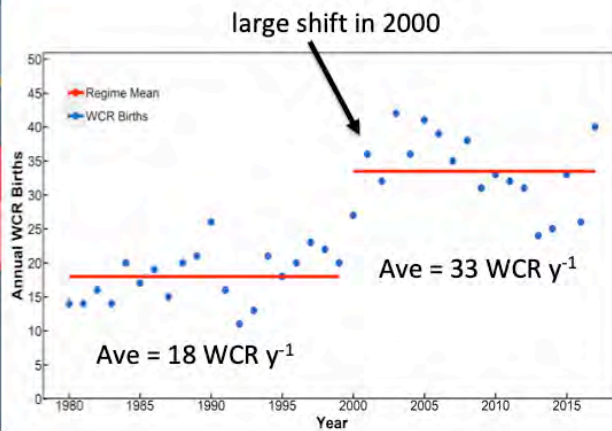
Gulf Stream behavior has changed since the 1990s

Size of Gulf Stream meanders has increased
 Meanders begin further to the west
 Meanders may come closer to Shelfbreak

The average number of warm core rings (WCR) formed each year from Gulf Stream meanders abruptly increased in 2000 from 18 to 33 rings



Adapted from Andres 2016



Monim, 2017

Gangopadhyay et al. 2019

Figure 4. The location where the Gulf Stream changes from a trapped boundary current to a meandering jet has shifted to the west ~ 1500 km (~800 nm) since the 1990s. Meander amplitudes have increased and the number of warm core rings pinching off meanders nearly doubled abruptly in the year 2000.

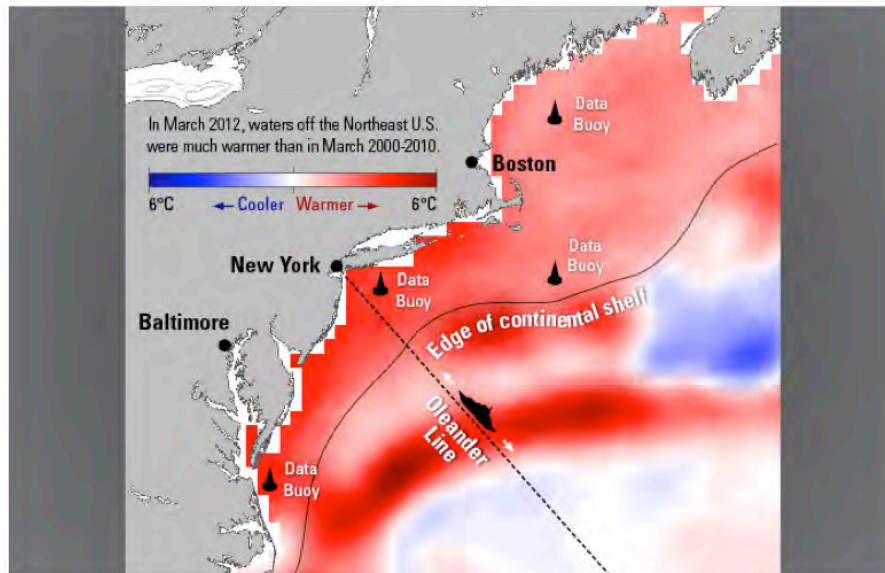
990 Over the past two decades profound changes in the dynamics of the Gulf Stream-Shelf
 Slope Sea-Continental shelf system have occurred that could influence the movements of
 juvenile and adult shortfin squid and/or the survivorship of early life history stages and
 population productivity. Glenn Gawarkiewicz of the Woods Hole Oceanographic
 Institute and Paula Fratantoni and Kim Hyde of the NOAA Northeast Fisheries Science
 995 Center led the discussion of changes in the oceanography of the Gulf Stream-Shelf Slope
 Sea-Continental shelf system.

1000 Since the 1990s the location where the Gulf Stream becomes unstable and changes from a
 trapped western boundary current to a meandering jet forming warm and cold core rings
 has shifted to the west and upstream from an area east of the New England Seamounts
 (~65°W longitude) approximately 500 km (800 nm) to the west (~75°W longitude) at a
 rate of about 25 km y⁻¹ (13.5 nm y⁻¹; Andres, 2016; Fig. 4). This westward shift in the
 destabilization point has been accompanied by an increase in the amplitudes (~200 km,
 110 nm) of wavelike Gulf Stream meanders (wavelengths~330 km, 180 nm) that translate
 1005 east at approximately 8 km d⁻¹ (~4 nm d⁻¹). In 2000, the number of warm core rings
 pinching off Gulf Stream meanders into the shelf slope sea abruptly increased from an
 average of 18 rings per year to 33 rings per year (Monim, 2017; Gangopadhyay et al.,

2019). Ring formation is seasonal with a peak from May through July. A similar increase in the number cold core rings forming on the south side of the Gulf Stream has not been observed. Warm salty Sargasso Sea and Gulf Stream water is trapped in the cores of warm core rings that translate to the southwest in the shelf slope sea at an average speed of 6.5 cm/sec (0.13 knots). The rings are 60 to 200km (30nm - 110 nm) in diameter, up to 1500 meters thick (250-800 fathoms) and have lifetimes ranging from 50 to over 200 days (mean lifetime 120d; Brown et al., 1986; Gaube and McGillicuddy, 2017). The westward destabilization of the Gulf Stream, increase in meander amplitudes, and increase in the frequencies of warm core rings has caused the mixed layer of the shelf slope sea to become warmer and saltier (Forsyth et al., 2015). These changes in the characteristics of Gulf Stream meanders, and the increase in frequencies warm core rings, including decaying rings, are likely to affect the upwelling dynamics and productivity of these features through a complex set of physical and biological mechanisms (see McGillicuddy, 2016; Gaube and McGillicuddy, 2017; McWilliams et al., 2019).

Atmospheric Influence

Extreme ocean warming in 2012 was driven by the Atmospheric Jet Stream



Courtesy Ke Chen WHOI

1025 **Figure 5. Interactions between the Atmospheric Jetstream and the Gulf Stream (oceanic jetstream) contributed to the development of an ocean heatwave on the continental shelf and slope sea in 2012 and the winter of 2017-2018.**

1030 Warm core rings that translate west and run aground on the continental slope significantly impact conditions and biological productivity on the continental shelf. The rings are too deep to move onto the shelf, but instead drive intrusions of warm salty water onto the shelf on the surface, as well as mid-depth and near the bottom. The influence of these intrusions can be detected on the shelf to depths as shallow as 30 meters (=15 fathoms).

Gulf Stream intrusions have contributed to the recent warming of shelf waters including the development of shelf heat waves in 2012 and 2017-18 (Chen et al., 2014; 1035 Gawarkiewicz et al., 2019). A warm core ring intrusion that moved onto the southern New England continental shelf south of Nantucket in January of 2017 was tracked as it moved southwest and was finally resorbed in the shelf slope sea in late April, just north of Cape Hatteras (Gawarkiewicz et al., 2019). Since 2003 continental shelf temperatures 1040 off the New Jersey coast have increased 5 times faster than from 1977 to 2013 and 15 times faster than from 1880 to 2004 (Forsyth et al., 2015). Warm core rings impinging on the outer edge of the continental shelf also affect the dynamics of the shelf break front, a sharp gradient in temperature and salinity that forms between continental shelf water and slope water. Warm core rings can cause compression of this gradient and the intensification and perhaps even reversals of the shelf slope jet current. Primary 1045 production near the shelf break is also dependent on upwelling associated with instabilities in the shelf-slope front and shelf-slope jet that warm core rings and intrusions contribute to (Siedlecki et al., 2011; Zhang et al., 2013).

Mechanisms underlying in the formation of Gulf Stream rings are complex and those 1050 causing recently observed changes in the characteristics of the Gulf Stream, its meanders and warm core rings, are not fully understood (Gangopadhyay et al., 2019; McWilliams et al., 2019). Gulf Stream dynamics have been linked to the North Atlantic Oscillation (NAO) which measures the strength of the normalized atmospheric pressure gradient between the Icelandic low and Azores high (Greene et al., 2013). Gulf Stream position, 1055 NAO, and storm tracks have been linked to Greenland blocking patterns and warming of the Arctic (Joyce et al., 2019). Ocean heat waves have been linked to decreases in the loss of heat from the ocean to the atmosphere due to changes in the path of the atmospheric jet stream (2012 heatwave; Gawarkiewicz et al., 2019). While the mechanisms are not fully understood it seems clear that the dramatic changes observed in 1060 the Gulf Stream-slope sea-continental system are related to changes in ocean-atmosphere dynamics that are attributed to anthropogenic global warming. These sorts of changes are evident in all the worlds oceans, including the North Atlantic Basin (Holliday et al., 2020; Yang et al., 2020). Given the importance of the Gulf Stream-slope sea-continental shelf system as habitat for northern Shortfin squid, particularly during early life history, it 1065 would be remarkable if the profound changes recently observed in the underlying physical dynamics of the system did not affect population dynamics.

5.1) Possible oceanographic mechanisms underlying changes in shortfin squid stock availability and/or productivity: Changes observed in the Gulf Stream-Slope Sea-Shelf 1070 system could increase the availability of northern shortfin squid to bottom trawl fisheries and fishery independent surveys through two mechanisms that are not mutually exclusive. First, if the warm core Gulf Stream rings and streamers provide efficient migration pathways from the shelf slope sea to the continental shelf for juvenile and adult squid, increases in the frequency of warm core rings and streamers could result in the 1075 immigration of a larger proportion of juvenile and adult squid from the slope sea onto the continental shelf. Fisherman report that opportunities for fishing in the early summer are

sometimes anticipated by warm core rings with trajectories that near the continental shelf (*section 6; Fig. 7*).

1080 Secondly, the observed changes in ocean dynamics could enhance nursery habitat
suitability, early survivorship and recruitment and thus population productivity. High
concentrations of larval squid occur in convergences associated with meanders and Gulf
Stream rings (*See section 4*). Upwelling occurs in Gulf Stream meander crests and
1085 decaying warm core rings (McGillicuddy, 2016; Gaube and McGillicuddy, 2017;
McWilliams et al., 2019). Enhanced primary and secondary productivity becomes
concentrated on downstream convergences on the “backs” of wavelike meanders and
outer edges of decaying warm core rings where high concentrations squid larvae have
been observed. Young squid associated with warm core rings translating southwest
1090 against the northeastward flow of the Gulf Stream are also likely to be retained within the
southern slope sea gyre. Increases in the amplitude of Gulf Stream meanders and
frequencies of warm core rings may have increased squid nursery habitat suitability by
increasing retention in the southern slope sea gyre, as well as habitat carrying capacities,
fueling rapid development and growth and reducing the incidence of intra-cohort
1095 cannibalism. Up to a threshold, exposure to the warming waters of the slope sea shelf and
shelf could also increase rates of development, reduce generation time and increase
intrinsic population growth rate and productivity. The smaller body sizes observed in US
waters would also be expected (Hendrickson and Showell, 2019). This scenario is
consistent with the hypotheses of Bakun and Csirke (1998), O'Dor (1998b) and O'Dor
(1998a)

1100

The coast-wide increases in both fishery landings and fishery independent survey
abundance indices (Tables 2 & 3) in US and Canadian waters suggest that the

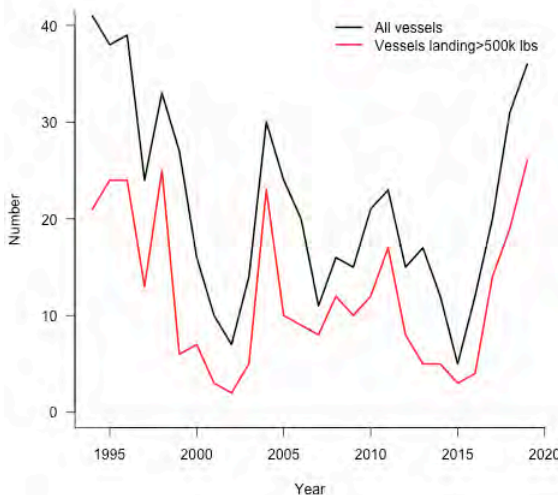


Figure 6. Total number of US vessels landing more than 10,000 lbs of shortfin squid (Black). Number of US vessels landing more than 500,000lbs per year indicated in red.

productivity of the northern shortfin squid population has increased. If the changes in squid availability observed had been related only to distribution shifts, abundance variations would be expected to have occurred at smaller scales matching those of mesoscale oceanographic features (~100-1000 km=54 – 500nm) likely affect movement pathways such as Gulf Stream rings and streamers.

6) Fishery perspectives on fishing effort, catch and shortfin squid ecology

Fishing effort and fishery observations of the behavioral ecology of targeted species are framed by the economics of fishing and constraints imposed on fishing practices by fishery technology and regulations. Shortfin squid is a highly

perishable seafood product targeted during warm summer months that sells for relatively low prices. To be profitable the fishery must land large volumes of squid that must be processed quickly. Economic and technological considerations involved in maintaining product quality as well as regulatory constraints are important factors that can decouple landings from population condition. Here, these issues are discussed before fishery observations of species population ecology. Discussion at the summit session also included a review of a draft survey to be administered to the fishery to identify factors affecting fishing effort (*Appendix 6*). This discussion is also described at the end of the section.

6.1 Overview of recent US and Canadian shortfin squid fisheries: Since 1999 when Canada stopped licensing foreign vessels, the US fishery has accounted for approximately 97% of the annual harvest of shortfin squid in the Northwest Atlantic (*Table 3*). Since then, the Canadian fishery has been a small commercial jig and recreational fishery operating mostly in the nearshore off Newfoundland. That fishery has accounted for a median of 3% of total landings in the North West Atlantic (0-33%) and has achieved only about 1% of the Total Allowable Catch for NAFO areas 3 and 4 (range 0-21%). Since 2016, 78-88% of the Canadian catches of squid were made in Newfoundland and Labrador waters (*Table 4*). Vessels less than 34 feet made 64-85% of these Canadian landings. Canadian landings have been low even during recent years when short fin squid abundance indices have been high in fishery independent surveys throughout the Northwest Atlantic, including Canadian waters (*Table 2*). Shoreside freezing and processing capacity is limited in Newfoundland where more valuable snow crab and capelin fisheries are given priority (James Barbera, Seafreeze LTD, Pers Comm). The low landings of squid in Canada are the result of limited processing capacity and economic opportunity costs.

The US fishery operates during the summer months on the southern New England and Mid atlantic Bight shelf break. Most vessels use large bottom trawls that have a maximum net height of 18 meters (10 fathoms) and 3 meter mesh (~10 foot meshes) in the mouth of the nets. This design maximizes herding of the squid while simultaneously minimizing the incidental catch of other species. Mechanized sorting of squid is not possible. Sorting other species from catches of squid by hand is not possible in the high volume fishery. Landings containing bycatch are offered low prices or not purchased at all by shoreside processors. Avoiding bycatch is made easier because other species usually do not mix into the large squid aggregations targeted by the fishery. As a result, the fishery is extremely clean. The fishery is prosecuted during good weather when large catches can be safely brought on board.

US Landings peaked and exceeded quotas in 1998, 2004, 2017, 2018 and 2019 (*Table 3*). Early fishery closures occurred during these years. According to fisherman, the fishing has been “exceptional” since 2017. During these years, the squid achieved larger body sizes earlier in the season, continued to increase in size and catch per unit effort steadily increased until the fishery closed. In 2019, large squid ~ 200g dominated catches at the end of the season. In earlier years smaller fish (100g) were more prevalent.

1170 In 2019 fishing was excellent in areas north and south of the Hudson shelf valley
throughout the season. Shelf waters were cool in the early summer of 2019, but warming
associated with a warm core ring nearing the New England shelf appeared to cause the
fishery to begin early in the north before beginning to the south (Fig. 5). During 2018
and 2019 high abundances of squid, high prices, changes in the nature of the fleet
described below, and the rapid rates at which landings approached quotas produced
1175 “derby fishing” conditions in the fishery. US Landings were low in the early 2000s and
2013-2016. The total number of vessels in the fleet is correlated with landings with a 0
and 1 year time lag (Fig. 4).

6.2 Impacts of economics & technical aspects on fishing effort

1180 Fisherman fish for dollars-not for fish. As a result fishing effort is determined by the
supply of and demand for squid in international and domestic markets and economic
opportunity costs. Prices and demand for northern Shortfin squid are set by supplies of
Argentine shortfin squid from a much larger international Falklands fishery that occurs
during the austral summer just preceding the US fishing season. Prices also depend on
supplies of flying squid (*Todarodes*) from the western Pacific. Squid supplies from the
1185 Falkland’s and western Pacific are influenced by the *El Niño* -Southern Oscillation
(*ENSO*), though fishing pressure from large international high seas fleets may also be
important. Foreign supplies of squid have been low in recent years leading to high prices
for northern Shortfin squid. In the past the US fishery supplied a food market in
Venezuela and bait markets. However international, and domestic US calamari markets
1190 for shortfin squid have recently expanded and contributed to increases in demand and
prices for high quality squid.

1195 Since 2016, ex-vessel prices for shortfin squid have fluctuated between \$1000-\$1200 per
metric ton. These prices are high but fishing effort is also determined by the value of
target stocks relative to the value of alternative stocks. Longfin squid sold for three times
as much (\$3000-\$3400 per metric ton) during the same period. In 2016, several fishing
operations opted to fish for longfin squid instead shortfin squid because longfin were
more available closer to shore in southern New England and commanded 3 times the
price. Only 5 vessels were responsible for shortfin squid landings in 2016 (Fig 4). The
1200 fishery operates on small profit margins. Small changes in fishing and processing costs
and prices of the squid and alternatives stocks significantly impact fishing effort.
Shortfin squid landings were relatively low in 2007-2008 and from 2013-2015. During
these years ex-vessel prices for shortfin squid were low while fuel prices spiked at over
\$3.50 per gallon.

1205 (https://static1.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/5cc1c0a824a694343e60a02a/1556201640568/2_2019+Illex+AP+Info+Doc.pdf;
https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=W_EPD2F_PRS_NUS_DPG&f=W)

1210 Because shortfin squid is an extremely perishable seafood product, shipboard and
shoreside processing capacities significantly impact fishing effort. Three different types
of vessels currently operate in the fishing fleet. Freezer vessels up to 165 feet long
perform onboard processing and freezing. Daily catch of these vessels is limited to a

1215 maximum of ~100,000 lbs (45 mt) per day due to processing limitations, but long
distance trips of long duration (up to 2 weeks) are possible depending on refrigerated
storage capacity. Vessels less than 165 feet with refrigerated seawater tank systems
(RSW) land up to 100,000-400,000 lbs per trip. They carry less than their maximum
capacities because 40% of the volume of tanks needs to be filled with chilled seawater to
1220 maintain the quality of the squid. Smaller RSW without tanks land up to 125,000-350,000
lbs a trip. The maximum duration of trips for vessels with refrigerated seawater is 48 to
72 hours because the squid must be processed and frozen at shoreside facilities quickly.
Some smaller vessels packing on ice also bring squid to shoreside facilities for processing
and freezing. These small vessels typically land 40,000 to 150,000 lbs of squid on trips
1225 that last no longer than 1-2 days. For vessels using refrigerated seawater systems or
packing on ice, fishing areas and trip durations are limited by the perishability of the
product and locations and capacities of shoreside facilities. These facilities are located in
5 ports; Hampton Virginia; Cape May, New Jersey; Pt. Judith, Rhode Island; New
Bedford and Gloucester, Massachusetts. Shoreside facilities processes 250,000 to 1
million pounds a day but often need to use some capacity for other species during the
1230 fishing season. Some of the processors operate 12 hour a day while others operate 24
hours. Shoreside processors often set limits on vessel landings (e.g. ~100mt) and
therefore limit fishing effort.

1235 The proportion of the different types of vessels in the fleet has not remained constant
over time. The first domestic freezer vessel came on line in 1984 and freezer trawlers
dominated the fleet through the early 2000s. Several smaller RSW vessels without tanks
and iceboats also operated in the fleet. In the last 5 years the proportion of high capacity
RSW vessels with tanks has increased. This group includes vessels that have converted
1240 from freezer processing to refrigerated seawater systems and shoreside processing. The
transition in the nature of the fleet has been made possible by increases in the capacity
and desire of shoreside facilities to process shortfin squid that can now be sold for
relatively high prices. The fleet transition has also been precipitated by the loss of
opportunities to fish for other stocks including Atlantic Mackerel and Atlantic Herring for
1245 vessels that possess or have been able to obtain permits for shortfin squid. Some
shoreside facilities that have also focused in the past on Herring and Mackerel processing
have shifted to processing the squid.

6.3 Effects of regulations on effort

1250 Fishery regulations have constrained effort in time and space. Early fishery closures have
occurred during years when landings exceeded harvest limits as described above.

1255 Spatial management regulations already described in *section 3.3.5 (Fig. 1)* have also
placed areas where significant amounts of shortfin squid have been caught in the past off
limits to the fleet. These areas include the 38,000 square nautical mile *Frank R.*
Lautenberg Deep-Sea Coral Protection Area, the 4,913 square mile *Northeast Canyons*
and Seamounts National Monument, the tilefish and lobster gear restricted areas, and
other regulated mesh areas in Southern New England and the Mid Atlantic Bight that
prohibit the use of fine mesh trawls used by the squid fishery. Mesh regulations also
prohibit fishing on areas Georges Bank and Nantucket Shoals. While other areas in the

- 1260 Gulf of Maine may permit fishing for shortfin squid using traditional nets, the New England ground fish catch shares system and bycatch regulations effectively prohibit squid fishing. Thus large areas of the Mid Atlantic Bight, Southern New England, and Gulf of Maine serve as reserves and areas of escapement for shortfin squid from the fishery.
- 1265 **6.4 Fishery observations of shortfin distribution, abundance and behavioral ecology**
Bottom trawl tows in the fishery are usually made during the daytime because the squid exhibit diel vertical migration and are usually concentrated near bottom during daylight hours (*section 4*). Catch per unit effort does not vary systematically between morning and evening twilight. Where permitted, the fishery is prosecuted along the outer edge of the continental shelf in southern New England and the mid Atlantic Bight at depths between 60-200 fathoms (109- 365 meters) and in bottom water temperatures as low as 46°F (8°C).
- 1270
- 1275 Northern shortfin squid exhibit shoaling and schooling behavior that fisherman compare to the murmurations of birds. Shoals can appear repeatedly in hotspots from year to year, but the squid also constantly change distributions and new waves immigrants move onto the shelf break. Over the last 5 years, the squid have been observed at sites where they have not been caught before. The availability of squid can change rapidly as the animals move cross shelf as well as along shelf. Vessels can go from full production to no production quickly even when environmental conditions including bottom temperatures appear unchanged. Following a complete disappearance, squid may aggregate again in the same location within a few days. Fisherman report that squid abundance on the shelf break varies at length scales of 5 to 10 nautical miles (10-20km) along shelf, 0.05 to 0.25 nautical miles (0.09- 0.5 km) cross shelf, and at time scales of 1-2 days. These space-time scales are similar to those characterizing the dynamics of the shelf slope front (Chen and He, 2010; Gawarkiewicz et al., 2018; Todd et al., 2013). Aggregations of dolphins, pilot whales, and fishing vessels also cause the squid to disperse. The squid aggregations can also reform in the same area after a few days.
- 1280
- 1285

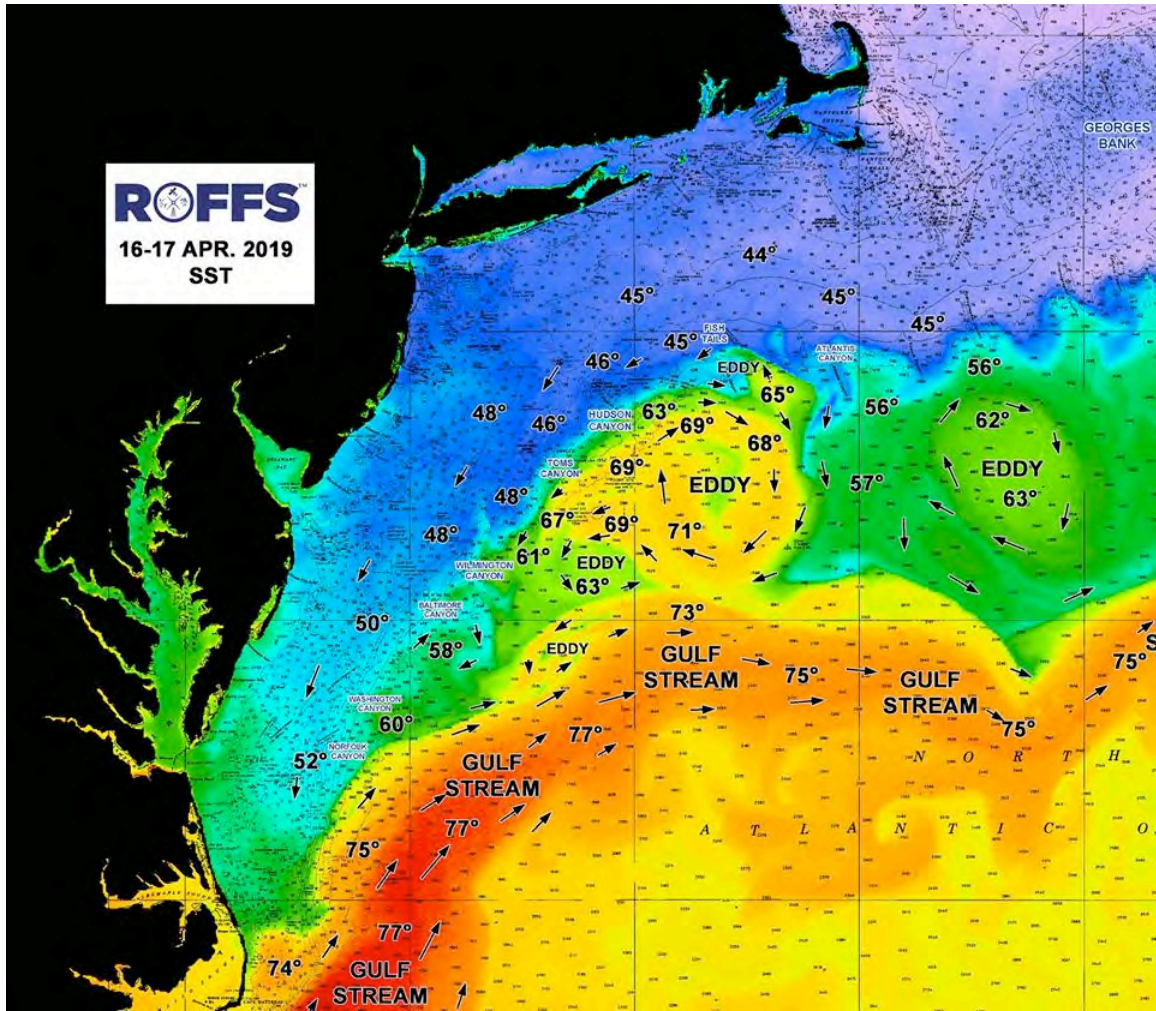


Figure 7. ROFFs analysis of SST and circulation in the Northwest Atlantic for mid April 2019. The movement of warm core eddy water toward cold continental shelf water was used by a fisherman to anticipate the start of shortfin squid fishing in May in the southern New England Canyons.

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Shortfin squid fisherman who fish for longfin squid and other species on the shelfbreak during the winter observe small juvenile shortfin squid tangled in net twine. Their observations suggest that spawning occurs year round and that the squid are widely distributed near the shelf break all year. Over the past few years the incidental catch of large shortfin squid in the winter shelf break fisheries has been relatively high. However fisherman state that the availability of shortfin squid during the winter does not forecast the availability of the squid during the following summer. Fishermen participating in the swordfish and tuna longline fisheries report seeing northern shortfin squid in the diets of predators caught on the south side of the Gulf Stream. Large squid with 3-4 foot tubes have been observed in the stomachs of swordfish caught in the slope sea and on both sides of the Gulf Stream.

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1310 During summers in which catches of shortfin squid have been exceptional, increasingly large squid dominate catches as the season progresses. In good years, landings may be accounted for by fewer numbers of larger, heavier squid on RSW and Ice boats as well as freezer trawlers. In poor years, squid are smaller and the size of fish remains relatively constant throughout the season. In 2016, the squid actually became smaller as the season progressed.

1315 The consensus among experienced fisherman attending the summit was that the availability of shortfin squid to the fishery was unpredictable and efforts to predict with certainty, distribution and abundance on the basis of easily observable environmental variation is a fools errand. Exceptional fishing in the 2017 season could not be predicted by fisherman on the basis the availability of squid during the summer of 2016, the
1320 incidental catch of shortfin squid in shelfbreak fisheries during the winter of 2016-2017, or using ocean observations. The best predictor of the immigration of large squid onto the shelf break during early summer are complaints of longliners overheard on the radio of squid eating the bait off the hooks of longlines set for large pelagics in the shelf slope sea and Gulf Stream. Good fishing seasons are sometimes marked by the early immigration
1325 of squid onto the bank. However this was not the case in 2019, which was an exceptional year.

1330 It is true that warm core Gulf Stream rings with trajectories that come near to the outer edge of the continental shelf sometimes anticipate the immigration of shortfin squid onto the shelf break (*Fig. 5*). Fisherman report that the timing, location of generation and size of the rings appears to be important. Warm core rings are thought to bring warm water to the shelf break that may provide pathways for the movement of squid from the shelveslope sea. However movements of squid do not always appear to be related to warm core rings and the relationship may have weakened in recent years.

1335 Fisherman have observed changes ocean temperatures on the outer edge of the continental shelf during recent years when the fishing has been excellent. In 2019 bottom temperatures were more variable over shorter distances than in the past, and very warm bottom temperatures were observed (up to 64°F = 18°C in October 2019). Temperatures
1340 as cold as 45.5°F (7.5°C) were also observed between warm surface and bottom layers. Cold midwater layers were used to preserve catches on freezer trawlers by hauling the net and keeping the codend midwater until the previous tow was processed

1345 ***6.5 Review of draft survey of fishery perspectives of factors driving fishing effort and stock condition***

The group discussed a survey drafted by Paul Rago to be administered to the fishery (*Appendix 6*). The goals of the survey are to 1) identify factors related to the practical aspects of squid fishing and processing including economics and regulations that might be useful for developing a standardized fishery catch per unit effort that is proportional to
1350 shortfin squid population size. The 2nd goal is to evaluate industry impressions of quality of specific fishing years (good, average or poor). Finally, the 3rd goal is to identify potential indicators of stock status not considered by fishery scientists that fisherman view as revealing.

1355 In the discussion about developing fishery dependent indicators of stock condition (*goal*
1), the complex set of factors affecting landings including economics and difficulties of
calculating CPUE in a fleet with such a diversity of fishing, processing and storage
capacities were addressed. This included the importance shoreside processing capacity
in controlling fishing effort. There are important nuances in fishing effort, including
1360 bottom time, distance towed, time between sets that vary with the availability of the
stock, as well as storage and or processing capacity of individual vessels that also need to
be monitored. It was agreed that the 2nd goal of developing a qualitative industry based
view of the history of stock status, which mirrors similar efforts in Europe to integrate
industry perspectives of stock condition into assessments, is a good idea. The relationship
1365 between trends in squid size during good and poor fishing years (see *section 6*), were
emphasized during the discussion of goal 3. The survey continues to developed as of the
date of this report was issued (3/3/2020).

1370 **7) Brief summary of relevant fishery dependent & independent data & resources
including collaborative industry-science assessment infrastructure available through
the NOAA/NEFSC Cooperative Research Branch Study Fleet**

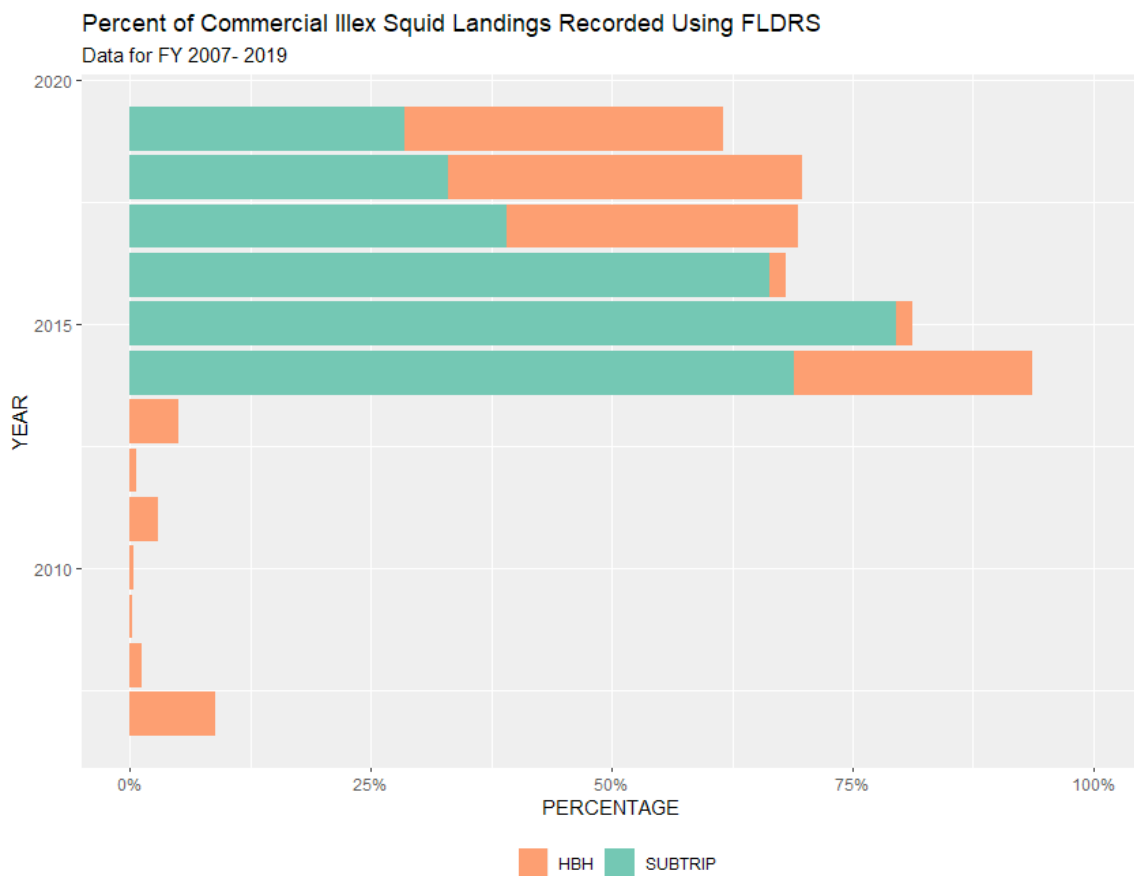
Fishery independent surveys traditionally used in the US and Canada to assess the
northern shortfin squid were identified. These included the Fall NEFSC multi-species
1375 bottom trawl surveys conducted between Cape Hatteras, North Carolina and the Gulf of
Maine during September-November, as well as the Canadian DFO surveys of the
southern Gulf of St. Lawrence during September (Div. 4T), the Scotian Shelf and Bay of
Fundy (Div. 4VWX) during July, and most of the Grand Banks during October-
December. A bottom trawl survey of the Flemish Cap conducted in July by the EU-
1380 Spain/Portugal is also relevant.

Northern Shortfin squid are seasonally abundant in the nearshore in the mid Atlantic
Bight, southern New England and the Gulf of Maine. As a result, coastal bottom trawl
surveys in the Northeast Area Monitoring and Assessment Program (NEAMAP) network
1385 (<http://www.neamap.net/>) are useful for identifying the area occupied by shortfin squid.
These surveys include a nearshore survey from Cape Hatteras to Rhode Island Sound
conducted collaboratively by the Virginia Institute of Marine Science and the Fishing
Industry, as well as coastal bottom trawl surveys conducted by the states of New Jersey,
New York, Rhode Island, Massachusetts, Maine and New Hampshire.

1390 The value of US fishery dependent data including Vessel Monitoring System records of
vessel movements, Dealer Reports, Vessel Trip Reports and Observer Data was also
discussed.

1395 Finally, since 2006, the NOAA/NEFSC Cooperative Research Branch has partnered with
many fishing vessels in the shortfin squid fleet and other fleets across the northeast region
to collect fine-scale catch, effort, and environmental data. Partner vessels use specialized
software, called FLDRS, to collect and transmit their data to the NOAA/NEFSC
Cooperative Research Branch (CRB). Since 2006, 28 fishing vessels have worked with

1400 CRB to collect fine-scale data on shortfin squid catch and effort (Fig. 8). This results in a
 1405 database consisting of haul-level shortfin squid catch, effort, and environmental data for
 1410 up to 450 trips per year. CRB maintains staff to support the technical needs of partner
 fishing vessels, as well as staff to manage and analyze the data. CRB recently increased
 capacity to address the need for additional research on the squid and, as a result, is
 collecting, standardizing, and analyzing the shortfin squid size records from dealers
 across the coast, as well as spearheading an analysis of the proportion of the shortfin
 squid population available to the US fishery (see below section 8). CRB recognizes the
 importance of working closely and developing trust with fishing industry partners. This is
 necessary if the science community is to develop the deep understanding of the shortfin
 squid fishery required for well informed ecosystem based fisheries science and
 management systems.



1415 **Figure 8. Proportion of total landings of shortfin squid reported using the NOAA/NEFSC Cooperative Research FLDRS software each year. Orange indicates percent of landings in which captains reported catches in each tow.**

8) Develop a framework for collaborative science products to address important uncertainties by the spring 2020

1420 This section describes discussions about science products that could inform fisheries management in the near term, as well as the processes that must be negotiated for the products to be reviewed by the Mid-Atlantic Council Science and Statistical Committee, and the Mid-Atlantic Council itself. The emphasis was placed on products that could

1425 inform MAFMC SSC recommendations to modify the ABC Acceptable Biological Catch (ABC) Control Rule by summer of 2020. One fisherman (K. Goodwin) pointed out that the squid have recently been present in high concentrations on the outer edge of the continental shelf through the autumn and could be profitably caught then. As a result management actions could impact the fishery even if they were implemented in the late summer and fall. The group agreed the projects should be designed on “*Do no harm basis*”, with the goal of not destabilizing the stock or the fishery.

1430 Research directions discussed including long term (2-5 yrs) and medium term (1-3 yrs) information rich investigations of 1) linkages between stock availability, productivity and ocean dynamics, 2) developing fishery dependent indicators of stock condition through real-time collaborative monitoring of fishing and processing operations using fishing industry and NOAA/NEFSC Cooperative Research Branch assets, 3) and an industry based survey of the outer continental shelf conducted when landings reach certain percentages of allocated quotas with the goal of providing stock condition indicators for in-season quota adjustment. 4) An investigation that could be feasibly completed within the near term (4-6 months) was also discussed and is described in more detail.

1440 The group was advised that the lead assessment scientist and an observational oceanographer are already pursuing research direction #1.

1445 The following topics, many of which are touched upon in *section 7*, were discussed with respect to realtime monitoring of the fleet:

- The degree of stratification of vessels required for analysis, from aggregation at the fleet level, stratification by processing type and capacity, or even stratification by individual vessel.
- Comparison of information content in tow by tow data versus trip level data for the calculation of fishery dependent catch per unit effort (CPUE).
- The need to explicitly account for variations in fishery selectivity, fishing mortality, natural mortality (including cannibalism), emigration, immigration, and recruitment in analyses of CPUE and size based indices of stock condition.
- It was agreed that collaboration with the industry is crucial for understanding the role of economics, regulations, processing and fishing capacity, as well the spatial dynamics of squid distribution and other characteristics in determining fishery CPUE and the degree to which CPUE reflects population condition. Some of this information could be developed using the survey described in *section 6* or a semi-structured interview approach with the goal of developing a deep understanding of socio-ecological factors driving fishing effort. Constraints on the government employees for administering surveys and interviews that are associated with the paperwork reduction act could be avoided if the industry itself administered this component. Field work within the active fishery is also required.

1465 In the discussion of the in-season survey (#3) it was proposed that three fishing vessels with the same nets and sampling protocols could be used simultaneously to perform a rapid, properly stratified survey for shortfin squid when landings reached 25%, 50%, and/or 75% of the quota. If the survey data indicated that the stock remaining was in

1470 good condition as the landings neared annual quota limits, the quota could be adjusted to extend the season. Otherwise the quota would remain in place.

1475 Finally much of the discussion focused on research product #4 that could be completed in within 4-6 months and potentially inform fishery management decisions in 2020. The product proposed by the group was to develop an *estimate of the proportion of the area occupied by Shortfin Squid accessed by the fishery in each year as a means to estimate the availability of the population to the fishery. This statistic could serve a maximum bound to fishing mortality (F). Its complement can be viewed as estimate of the area of escapement of the shortfin squid stock from the fishery.* The product was designed to address the flawed assumption implicit in harvest policy since 1998 that %100 of the northern Shortfin Squid Stock is available to the US fishery. Additional stock condition indicators supporting the analysis were also suggested.

1485 *Rational and Logic:* Shortfin squid live less than one year, die just after spawning, and recruitment is variable and environmentally controlled (*section 3*). As a result the focus of stock assessment and fishery management has been to develop approaches ensuring that sufficient numbers of mature squid escape the fishery each year to provide for successful recruitment in the next year (*section 2*).

1490 The squid range from south of Cape Hatteras to Labrador and occupy continental shelf to slope sea habitats which they use as spawning, nursery and feeding grounds (Jereb and Roper, 2010a; O'Dor and Dawe, 2013). The proportion of the stock that uses the mid US and Canadian Shelf as a feeding ground is believed to migrate onto the shelf in a wavelike pattern not through single chokepoints on the continental shelf where the stock could be disproportionately vulnerable to fisheries (see *section 4.4*). Under the assumption that the squid move onto and off of the shelf in waves and movements on the shelf do not occur through chokepoints, the vulnerability of the squid to the fishery can be roughly approximated in two spatial dimensions in each year by the ratio of the area fished, A_f , to the area occupied by the species, A_o . This is a spatial estimate of the proportional availability $\rho = A_f/A_o$ of the stock to the fishery. This index of availability can be used as a proxy for estimating a maximum bound to proportional fishing mortality F_{proxy} if the assumptions hold. The complement of $1-p$, or $1 - A_f/A_o$, is the proportion of the area occupied by the species that has not been fished. This statistic can be viewed as a spatial index of proportional escapement of the species from the fishery. Estimates of ρ and $1 - \rho$ are most accurate if they account for the probabilities of occupancy of the species and fishery at fine grains within and outside of areas of co-occurrence.

1510 The group was advised to adopt a conservative approach to developing estimates of the availability of the stock to the fishery (ρ), and proportional escapement ($1-p$) by confining the analysis to fishery and fishery independent survey data collected in US continental shelf waters where the fishery is well monitored and routine bottom trawl surveys performed. The shelf slope sea is not routinely surveyed. Although shelf wide bottom trawl surveys are conducted in Canada where the squid has been abundant (table 3) the Canadian fishery is not well monitored (Hendrickson and Showell, 2019). Further the group was advised to develop estimates of the area fished (A_f) by the US fleet using the

1515 standard method for mapping the distributions of fishery landings for trips greater than
4.5 mt (10,000 lbs) by ten-minute squares (~10 x 10 nm). Fishing operations occur at
much smaller horizontal length scales (*see section 6*). The conservative approach
recommended will yield estimates of availability to the fishery (ρ) and F_{\max} that are
1520 higher than true values while estimates of the proportional escapement ($1-\rho$) of fish from
the fishery will be lower than the true state of nature.

Other indicators of stock condition that could serve as auxiliary information for this
product were discussed including

- Indices of annual trends in shortfin squid growth and body size
- 1525 - Fishery dependent CPUE indices
- Ecosystem indicators related to processes likely to impact stock productivity
- Economic indicators likely to impact fishing effort that are unrelated to stock
availability
- Management indicators

1530

8.1) Process & deadlines required for timely product review

The group also discussed the processes required and deadlines that must be met for
research products to be reviewed. To be considered by the MAFMC SSC, the product
development needed to be completed and submitted by March 2-3, 2020 to Brandon
1535 Muffley, Fishery Management Specialist at the MAFMC (bmuffley@mafmc.org) so that
it can be reviewed by the SSC. The group was advised that Jason Didden (MAFMC
Staff), Paul Rago (MAFMC SSC), Sara Gaiches (MAFMC SSC) and Mike Wilberg
(MAFMC SSC) who were present at the summit should be kept in the loop. The council
would need to be notified about the product and its implications “early”. Communication
1540 with the council should be made through Jason Didden. Finally the MAFMC SSC and
council need to be assured that products can be delivered to the SSC in future years.

The meeting was adjourned.

- 1545 *Liturature* cited
- Andres, M. 2016. On the recent destabilization of the Gulf Stream path downstream of Cape Hatteras. *Geophysical Research Letters*, 43: 9836-9842.
- 1550 Angilletta Jr, M. J. 2009. *Thermal adaptation: A theoretical and Empirical Synthesis*, Oxford University Press, New York.
- Bakun, A., and Csirke, J. 1998. Environmental process and recruitment variability. *In* Squid recruitment dynamics. The genus *Illex* as a model. The commercial *Illex*. Influences on variability, pp. 105-124. Ed. by P. G. Rodhouse, E. G. Dawe, and R. K. O'Dor. , FAO Fisheries Technical Paper
- 1555 Brodziak, J., and Hendrickson, L. 1998. An analysis of environmental effects on survey catches of squids *Loligo pealei* and *Illex illecebrosus* in the northwest Atlantic. *Fisheries Bulletin*, 97: 9-24.
- Brown, O. B., Cornillon, P. C., Emmerson, S. R., and Carle, H. M. 1986. Gulf Stream warm rings: a statistical study of their behavior. *Deep Sea Research Part A*.
- 1560 Oceanographic Research Papers, 33: 1459-1473.
- Chen, K., Gawarkiewicz, G. G., Lentz, S. J., and Bane, J. M. 2014. Diagnosing the warming of the Northeastern U.S. Coastal Ocean in 2012: A linkage between the atmospheric jet stream variability and ocean response. *Journal of Geophysical Research: Oceans*: n/a-n/a. DOI: <http://dx.doi.org/10.1002/2013JC009393>
- 1565 Chen, K., and He, R. 2010. Numerical Investigation of the Middle Atlantic Bight Shelfbreak Frontal Circulation Using a High-Resolution Ocean Hindcast Model. *JOURNAL OF PHYSICAL OCEANOGRAPHY*, 40: 949-964.
- Chen, K., and He, R. 2015. Mean circulation in the coastal ocean off northeastern North America from a regional-scale ocean model. *Ocean Sci.*, 11: 503-517.
- 1570 Cho, B. C., and F. Azam 1990. Biogeochemical significance of bacterial biomass in the ocean's euphotic zone. *Marine Ecology Progress Series*, 63: 253-259.
- Csanady, G. T., and Hamilton, P. 1988. Circulation of slope water. *Continental Shelf Research*, 8: 565-624.
- Dawe, E. G., and Beck, P. C. 1985. Distribution and Size of Short-finned Squid (*Illex illecebrosus*) Larvae in the Northwest Atlantic from Winter Surveys in 1969, 1981 and 1982. *Journal of Northwest Atlantic Fisheries Science*, 6: 43-55.
- 1575 Dawe, E. G., and Beck, P. C. 1997. Population structure, growth, and sexual maturation of short-finned squid (*Illex illecebrosus*) at Newfoundland. *Canadian Journal of Fisheries and Aquatic Sciences*, 54: 137-146.
- 1580 Dawe, E. G., Colbourne, E. B., and Drinkwater, K. F. 2000. Environmental effects on recruitment of short-finned squid (*Illex illecebrosus*). *ICES Journal of Marine Science*, 57: 1002-1013.
- Dawe, E. G., Hendrickson, L. C., Colbourne, E. B., Drinkwater, K. F., and Showell, M. A. 2007. Ocean climate effects on the relative abundance of short-finned (*Illex illecebrosus*) and long-finned (*Loligo pealeii*) squid in the northwest Atlantic Ocean. *FISHERIES OCEANOGRAPHY*, 16: 303-316.
- 1585 DeMont, M. E., and O'Dor, R. K. 1984. The effects of activity, temperature and mass on the respiratory metabolism of the squid, *Illex illecebrosus*. *Journal of the Marine Biological Association of the United Kingdom*, 64: 535-543.
- 1590 Dunne, S. 2017. Managing the Southwest Atlantic: the case of *Illex argentinus*. *In* School

- of GeoSciences. University of Edinburgh,, Scotland.
- Durward, R., Vessey, E., O’Dor, R., and Amaratunga, T. 1989. Reproduction in the squid, *Illex illecebrosus*: first observations in captivity and implications for the life cycle. Sel. Pap. ICNAF., 6: 7–13.
- 1595 Forsyth, J. S. T., Andres, M., and Gawarkiewicz, G. G. 2015. Recent accelerated warming of the continental shelf off New Jersey: Observations from the CMV Oleander expendable bathythermograph line. Journal of Geophysical Research: Oceans, 120: 2370-2384.
- 1600 Gangopadhyay, A., Gawarkiewicz, G., Silva, E. N. S., Monim, M., and Clark, J. 2019. An Observed Regime Shift in the Formation of Warm Core Rings from the Gulf Stream. Scientific Reports, 9: 12319.
- Gaube, P., and McGillicuddy, D. J. 2017. The influence of Gulf Stream eddies and meanders on near-surface chlorophyll. Deep Sea Research Part I: Oceanographic Research Papers, 122: 1-16.
- 1605 Gawarkiewicz, G., Chen, K., Forsyth, J., Bahr, F., Mercer, A. M., Ellertson, A., Fratantoni, P., et al. 2019. Characteristics of an Advective Marine Heatwave in the Middle Atlantic Bight in Early 2017. Frontiers in Marine Science, 6: 712.
- Gawarkiewicz, G., Todd, R. E., Zhang, W., Partida, J., Gangopadhyay, A., Monim, M.-U.-H., Fratantoni, P., et al. 2018. The Changing Nature of Shelf-Break Exchange Revealed by the OOI Pioneer Array. Oceanography, 31.
- 1610 Greene, C. H., Erin Meyer-Gutbrod, Monger, B. C., Louise P. McGarry, Andrew J. Pershing, Igor M. Belkin, Paula S. Fratantoni, et al. 2013. Remote climate forcing of decadal-scale regime shifts in Northwest Atlantic shelf ecosystems. Limnology and Oceanography, 58: 803-816.
- 1615 Harrop, J., Vecchione, M., and Felley, J. D. 2014. In situ observations on behaviour of the ommastrephid squid genus *Illex* (Cephalopoda: Ommastrephidae) in the northwestern Atlantic. Journal of Natural History, 48: 2501-2516.
- Hatanaka, H. 1986. Body Size of Short-finned Squid *Illex illecebrosus* Larvae in the Northwest Atlantic. Nippon Suisan GAKKAISHI, 52: 19-22.
- 1620 Hatanaka, H., Lange, A. M. T., and T., A. 1984. Geographical and vertical distribution of shortfinned squid (*Illex illecebrosus*) larvae in the northwest Atlantic. Northwest Atl. Fish. Organ. (NAFO) Sci. Counc. Stud. , 9/123: 93-99.
- Hendrickson, L. C. 2004. Population biology of northern shortfin squid (*Illex illecebrosus*) in the Northwest Atlantic Ocean and initial documentation of a spawning area. ICES Journal of Marine Science: Journal du Conseil, 61: 252-266.
- 1625 Hendrickson, L. C., and Hart, D. R. 2006. An age-based cohort model for estimating the spawning mortality of semelparous cephalopods with an application to per-recruit calculations for the northern shortfin squid, *Illex illecebrosus*. Fisheries Research, 78: 4-13.
- 1630 Hendrickson, L. C., and Holmes, E. M. 2004. Essential fish habitat source document: northern shortfin squid, *Illex illecebrosus*, life history and habitat characteristics (2nd edition). . ICES Document 191. 36 pp.
- Hendrickson, L. C., and Showell, M. A. 2019. 2019 Assessment of Northern Shortfin Squid (*Illex illecebrosus*) in Subareas 3+4. Northwest Atlantic Fisheries Organization, Serial No. N6973.
- 1635 Holliday, N. P., Bersch, M., Berx, B., Chafik, L., Cunningham, S., Florindo-López, C.,

- Hátún, H., et al. 2020. Ocean circulation causes the largest freshening event for 120 years in eastern subpolar North Atlantic. *Nature Communications*, 11: 585.
- 1640 Ibáñez, C. M., and Keyl, F. 2010. Cannibalism in cephalopods. *Reviews in Fish Biology and Fisheries*, 20: 123-136.
- Jereb, P., and Roper, C. F. E. e. 2010. Cephalopods of the world. An annotated and illustrated catalogue of cephalopod species known to date. Volume 2. cMyopsid and Oegopsid Squids. *In* *FAO Species Catalogue for Fishery Purposes*. Ed. by FAO. Rome.
- 1645 Joyce, T. M., Kwon, Y.-O., Seo, H., and Ummenhofer, C. C. 2019. Meridional Gulf Stream Shifts Can Influence Wintertime Variability in the North Atlantic Storm Track and Greenland Blocking. *Geophysical Research Letters*, 46: 1702-1708.
- Jullion, L., Heywood, K. J., Naveira Garabato, A. C., and Stevens, D. P. 2009. Circulation and Water Mass Modification in the Brazil–Malvinas Confluence. *JOURNAL OF PHYSICAL OCEANOGRAPHY*, 40: 845-864.
- 1650 Kingsolver, J. G., and Huey, R. B. 2008. Size, temperature, and fitness: three rules. *Evolutionary Ecology Research*, 10: 251–268.
- Logan, J. M., and M.E., L. 2013. Assessment of trophic dynamics of cephalopods and large pelagic fishes in the central North Atlantic Ocean using stable isotope analysis. *Deep Sea Research*, 95: 63-73.
- 1655 Lowerre-Barbieri, S., DeCelles, G., Pepin, P., Catalán, I. A., Muhling, B., Erisman, B., Cadrin, S. X., et al. 2017. Reproductive resilience: a paradigm shift in understanding spawner-recruit systems in exploited marine fish. *FISH and FISHERIES*, 18: 285-312.
- 1660 McGillicuddy, D. J. 2016. Mechanisms of Physical-Biological-Biogeochemical Interaction at the Oceanic Mesoscale. *Annual Review of Marine Science*, 8: 125-159.
- McWilliams, J. C., Gula, J., and Molemaker, M. J. 2019. The Gulf Stream North Wall: Ageostrophic Circulation and Frontogenesis. *JOURNAL OF PHYSICAL OCEANOGRAPHY*, 49: 893-916.
- 1665 Monim, M.-U.-H. 2017. Seasonal and Inter-annual Variability of the Gulf Stream Warm Core Rings from 2000 to 2016. *In* *Department of Estuarine and Ocean Sciences*, p. 124. University of Massachusetts Dartmouth.
- Nakata, J. 1993 Long-term changes in catch and biological features of Japanese common squid (*Todarodes pacificus*) in waters off the east coast of Hokkaido. *In* *Recent Advances in Cephalopod Fisheries Biology*, pp. 343-350. Ed. by T. Okutani, R. K. O'Dor, and T. Kubodera. Takai University Press, Tokyo.
- 1670 NEFSC. 1996a. Report of the 20th Northeast Regional Stock Assessment Workshop (20th SAW). *ICES Document* 18: 95.
- 1675 NEFSC. 1996b. A report of the 21st Northeast Regional Stock Assessment Workshop. 96-05d.
- NEFSC. 1999. A report of the 29th Northeast Regional Stock Assessment Workshop.
- NEFSC. 2006. 42nd Northeast Regional Stock Assessment Workshop (42nd SAW) stock assessment report, part A: silver hake, Atlantic mackerel, and northern shortfin squid
- 1680 O'Dor, R. K. 1998a. Can understanding squid life-history strategies and recruitment improve management? *South African Journal of Marine Science*, 20: 193-206.

- O'Dor, R. K. 1998b. Squid life-history strategies. *In* Rodhouse, P.G.; Dawe, E.G.; O'Dor, R.K. (eds.) Squid recruitment dynamics. The genus *Illex* as a model. The commercial *Illex* species. Influences on variability. FAO Fisheries Technical Paper. No. 376. Rome, FAO. 1998. 273p.
- 1685 O'Dor, R. K., and Dawe, E. G. 2013. *Illex illecebrosus*, Northern Short-finned Squid. *In* Advances in Squid Biology, Ecology and Fisheries. Ed. by R. Rosa, G. Pierce, and R. O'Dor.
- 1690 Ogawa, Y., and Sasaki, T. 1988. Catch-fluctuation patterns of *Todarodes pacificus* (Steenstrup) in northern Japanese coastal waters of the Pacific Ocean. Bull. Tohoku reg. Fish. Res. Lab., 50: 1-24.
- Perez, J. A. A. 1995. The early life history of the short-finned squid, *Illex illecebrosus* (Cephalopoda: Ommastrephidae), as reconstructed from the gladius structure. Dalhausie.
- 1695 Perez, J. A. A., and O'Dor, R. K. 1998. The impact of environmental gradients on the early life inshore migration of the short-finned squid *Illex illecebrosus*. S. Afr. J. mar. Sci., 20: 293–303.
- 1700 Pitcher, T., Morato, T., Hart, P., Clark, M., Haggan, N., and Santos, R. 2007. Seamount: Ecology, Fisheries & Conservation.
- Politis, P. J., Galbraith, J. K., Kostovick, P., and Brown, R. W. 2014. Northeast Fisheries Science Center bottom trawl survey protocols for the NOAA Ship Henry B. Bigelow US Dept Commer 14-06. 138 pp.
- Pörtner, H. O. 1997. Oxygen limitation of metabolism and performance in pelagic squid, The responses of marine organisms to their environments. *In* Proc 30th European Marine Biology Symposium Ed. by S. H. L E Hawkins, with A C Jensen, M Sheader, J A Williams, eds University of Southampton, Chichester .
- 1705 Rathjen, W. F. 1981. Exploratory squid catches along the continental slope of the Eastern United States. Journal of Shellfish Research, 1: 153-159.
- 1710 Regniere, J., Powell, J., Bentz, B., and Nealis, V. 2012. Effects of temperature on development, survival and reproduction of insects: Experimental design, data analysis and modeling. Journal of Insect Physiology, 58: 634-647.
- Régnière, J., St-Amant, R., and Duval, P. 2012. Predicting insect distributions under climate change from physiological responses: spruce budworm as an example. Biol Invasions, 14: 1571–1586.
- 1715 Rivard, D., Hendrickson, L. C., and Serchuk, F. M. 1998. Yield Estimates for Short-finned Squid (*Illex illecebrosus*) in SA 3-4 From Research Vessel Survey Relative Biomass Indices.
- 1720 Roper, C. F. E., Lu, C. C., and Vecchione, M. 1998. A Revision of the Systematics and Distribution of *Illex* Species (Cephalopoda: Ommastrephidae). *In* Systematics and Biogeography of Cephalopods Ed. by N. A. Voss, M. Vecchione, R. B. Toll, and M. J. Sweeney.
- Rowell, T. W., Trites, R. W., and Dawe, E. G. 1985. Distribution of short-finned squid (*Illex illecebrosus*) larvae and juveniles in relation to the Gulf Stream frontal zone between Florida and Cape Hatteras. NAFO scient. Coun. Stud., 9: 77–92.
- 1725 Secor, D. H. 2002. Historical roots of the migration triangle. ICES Marine Science Symposia, 215.
- Secor, D. H. 2015. Migration Ecology of Marine Fishes, John Hopkins University Press,

- Baltimore, 2015. 292 pp.
- 1730 Seibel, B. A. 2007. On the depth and scale of metabolic rate variation: scaling of oxygen consumption rates and enzymatic activity in the Class Cephalopoda (Mollusca). *Journal of Experimental Biology*, 210: 1-11.
- Seibel, B. A., and Deutsch, C. 2019. Oxygen supply capacity in animals evolves to meet maximum demand at the current oxygen partial pressure regardless of size or temperature. *bioRxiv*: 701417.
- 1735 Shea, E. K., Judkins, H., Staudinger, M. D., Dimkovikj, V. H., Lindgren, A., and Vecchione, M. 2017. Cephalopod biodiversity in the vicinity of Bear Seamount, western North Atlantic based on exploratory trawling from 2000 to 2014. *Marine Biodiversity*, 47: 699-722.
- 1740 Siedlecki, S. A., Archer, D. E., and Mahadevan, A. 2011. Nutrient exchange and ventilation of benthic gases across the continental shelf break. *Journal of Geophysical Research: Oceans*, 116.
- Southwood, T. R. E. 1977. Habitat, the template for ecological strategies? *Journal of Animal Ecology*, 46: 377-365.
- 1745 Sprules, W. G., and Barth, L. E. 2015. Surfing the biomass size spectrum: some remarks on history, theory, and application. *Canadian Journal of Fisheries and Aquatic Sciences*, 73: 477-495.
- Takahara, H., Kidokoro, H., and Sakurai, Y. 2017. High temperatures may halve the lifespan of the Japanese flying squid, *Todarodes pacificus*. *Journal of Natural History*, 51: 2607-2614.
- 1750 Todd, R. E., Gawarkiewicz, G. G., and Owens, W. B. 2012. Horizontal Scales of Variability over the Middle Atlantic Bight Shelf Break and Continental Rise from Finescale Observations. *JOURNAL OF PHYSICAL OCEANOGRAPHY*, 43: 222-230.
- 1755 Trites, A. W. 1983. Physical Oceanographic Features and Processes Relevant to II/ex illecebrosus Spawning in the Western North Atlantic and Subsequent Larval Distribution NAFO Sci. Coun. Studies, 6: 39-55.
- Turchin, P. 2003. *Complex population dynamics: A Theoretical/Empirical Synthesis*, Princeton.
- 1760 Vecchione M, and G., P. Midwater cephalopods in the western North Atlantic Ocean off Nova Scotia *Bull Mar Sci*, 71: 883–892.
- Vidal, E., and Haimovici, M. 1998. Feeding and the Possible Role of the Proboscis and Mucus Cover in the Ingestion of Microorganisms by Rhynchoteuthion Paralarvae (Cephalopoda: Ommastrephidae). *BULLETIN OF MARINE SCIENCE*, 63: 305-316.
- 1765 Winemiller, K. O. 2005. Life history strategies, population regulation, and implications for fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences*, 62: 872-885.
- Yang, H., Lohmann, G., Krebs-Kanzow, U., Ionita, M., Shi, X., Sidorenko, D., Gong, X., et al. 2020. Poleward shift of the major ocean gyres detected in a warming climate. *Geophysical Research Letters*, n/a: e2019GL085868.
- 1770 Zhang, W. G., McGillicuddy, D. J., and Gawarkiewicz, G. G. 2013. Is biological productivity enhanced at the New England shelfbreak front? *Journal of Geophysical Research: Oceans*, 118: 517-535.

Appendices

Appendix table 1. Attendees of the Northern shortfin squid (*Illex Illecebrosus*) population ecology & the fishery Summit, November 25-26, 2019. Wakefield Rhode Island

Last Name	First Name	Expertise	Institution
Almeida	Katie	Fishery-Government Relations	The Towndock
Anoushian	Walter	Fishery Policy	NOAA GARFO
Axelson	Leif	Fisherman Ecologist	FV Dyrsten, Axelson & Sons
Axelson	Steve	Fisherman Ecologist	FV Flicka Axelson & Sons
Bright	Bill	Fisherman Ecologist	FV Retriever
Christel	Doug	Fishery Policy	NOAA GARFO
Clarke	Ryan	Processor/Dealer/Marketing	The Towndock
Didominico	Greg	Fishery-Government Relations	Garden State Seafood
Fox	Donald	Fleet management	The Towndock
Frantantoni	Paula	Physical Oceanography	NOAA/NEFSC
Gaichas	Sarah	Fishery ecosystem scientist	NOAA/NEFSC
Goodwin	Glenn	Fisherman Ecologist, Fisheries Economics & Markets	FV, RELENTLESS, Seafreeze ltd
Goodwin	Kyle	Fisherman Ecologist	FV, PERSISTENCE, Seafreeze ltd
Gwierkewicz	Glenn	Oceanography	Woods Hole Oceanographic
Hughes	Peter	Policymaker, Fishery Gov't relations	MAFMC-SMB chair/Atlantic Capes Seafood
Hyde	Kim	Oceanography	NOAA/NEFSC
Kaelin	Jeff	Fishery-Government relations	Lunds fisheries
Lackner	Hank	Fisherman Ecologist	FV Jason Danielle
Lapp	Meghan	Fishery-Government relations	Seafreeze Ltd
Malik-			
Mercer	Anna	Fishery Scientist	NOAA/NEFSC Coop Research
Manderson	John	Fishery ecosystem scientist	OpenOcean Research
McNamee	Jason	Assessment Scientist/NEFMC SSC Chair	RI division Marine fisheries
O'Connor	Leah	Fishery Policy	NOAA GARFO

Pessutti	Jeff	Fishery Scientist	NOAA/NEFSC Coop Research
Pitts	Aly	Policy maker	NOAA GARFO
Rago	Paul	Assessment Scientist - MAFMC SSC	Independent
Reichle	Wayne	Processor/Dealer/Marketing	Lunds Fisheries
Reid	Eric	Gov't relations/Marketing/Processing	Seafreeze Ltd
Roderick	Mike	Processor/Dealer/Marketing	The Towndock
Ruhle	Jim	Fisherman Ecologist	FV Dyranna R
Ruhle	Phil	Fisherman Ecologist	FV Prevail, Seafreeze Ltd
			Chesapeake Biological Laboratory, U
Wilberg	Mike	Assessment Scientist, MAFMC SSC	Maryland
Wright	Brook	Fisheries Science	NOAA/NEFSC SMASS
Pavlowich	Tyler	Fisheries Science	NOAA/NEFSC

Appendix Table 2. Agenda for the Northern Shortfin Squid Population Ecology & the Fishery Summit. South Kingston, Rhode Island

Time Day 1: November 25

9:30 Introductions & goal of the summit

9:40 Current scientific basis of *Illex* management & review of past assessments.

10:40 Break

Review of *Illex* population ecology: Known knowns, known unknowns, & unknown unknowns.

10:50 Review Northwest Atlantic Oceanography possibly impacting *Illex* availability & productivity

11:50 Lunch

12:30 Possible mechanisms underlying stock availability and/or productivity responses to oceanographic change.

13:00 Review available collaborative industry-science assessment infrastructure in the region

13:40 Break

14:20 History of industry observations of shortfin squid: Migration and movements. Targetting, catchability. Observations of Size & Growth.

14:30 Discussion of economics, regulation & impacts on fishing effort & catch.

15:20 Industry self-monitoring for business that could reduce scientific uncertainty.

16:10 Break

16:20 Outline framework for development of science products to address important uncertainties by spring 2020

17:10 Adjourn & Dinner

Time Day 2: November 26

Review outlined framework for science products to address uncertainties by spring 2020

8:30 Brief summary of existing fishery dependent & independent data & resources
9:00 Continue development of framework & products that could impact 2020 fishin

9:20 season

11:20 Break

11:30 Process & deadlines required for timely product review

12:30 Adjourn

Appendix table 3. References provided to attendees prior to the Northern Shortfin Squid population ecology and the fishery summit

1785

Assessment and management documents

The April 2019 Mid Atlantic Fisheries Management Council (MAFMC) Fishery information document

1790 https://static1.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/5cc1c0a824a694343e60a02a/1556201640568/2_2019+Illex+AP+Info+Doc.pdf

The April 2019 MAFMC Fishery Performance Report

1795 https://static1.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/5cc1e39de2c483bb7201649e/1556210590292/2019+MSB_FPR.pdf

The 1996 Assessment that includes model output that has framed the development of quotas since the MAFMC passed Amendment 8 in 1998 to bring the Fisheries Management Plan into Compliance with the Sustainable Fisheries Act.

1800 NEFSC. 1996. Report of the 21st Northeast Regional Stock Assessment Workshop. 96-05d. <https://www.nefsc.noaa.gov/publications/crd/pdfs/crd9605d.pdf>. Starts on Pg. 42

The last full benchmark assessment 2006 with the state of the art of various assessment approaches including an in-season assessment. NEFSC. 2006. 42nd Northeast Regional Stock Assessment Workshop (42nd SAW) stock assessment report, part A: silver hake, Atlantic mackerel, and northern shortfin squid.

1805 <https://www.nefsc.noaa.gov/publications/crd/crd0609/pdfs/c.pdf>

Review of NWA Illex fishery and other Squid fisheries

1810 Arkhipkin, A. I., Rodhouse, P. G. K., Pierce, G. J., Sauer, W., Sakai, M., Allcock, L., Arguelles, J., et al. 2015. World Squid Fisheries. Reviews in Fisheries Science & Aquaculture, 23:92-252. (See pgs 103-109).

Reviews of Illex population ecology

1815 O'Dor, R. K., and Dawe, E. G. 2013. Illex illecebrosus, Northern Short-finned Squid. In Advances in Squid Biology, Ecology and Fisheries. Ed. by R. Rosa, G. Pierce, and R. O'Dor.

https://www.dropbox.com/s/sgyf2n8rpztaqip/ODor%26Dawe_2013.pdf?dl=0

1820 Hendrickson, L. C., and Holmes, E. M. 2004. Essential fish habitat source document: northern shortfin squid, Illex illecebrosus, life history and habitat characteristics (2nd edition). 191. 36 pp.

Reviews of Changes in NWA Oceanography and potential environmental impacts on Squid

1825 NOAA Northeast Integrated Ecosystem Assessment. State of the Ecosystem Reports <https://www.integratedecosystemassessment.noaa.gov/regions/northeast/reports>

- 1830 Gawarkiewicz, G., Todd, R. E., Zhang, W., Partida, J., Gangopadhyay, A., Monim, M.-U.-H., Fratantoni, P., et al. 2018. The Changing Nature of Shelf-Break Exchange Revealed by the OOI Pioneer Array. *Oceanography*, 31.
<https://tos.org/oceanography/article/the-changing-nature-of-shelf-break-exchange-revealed-by-the-ooi-pioneer-arr>
- 1835 Andres, M. 2016. On the recent destabilization of the Gulf Stream path downstream of Cape Hatteras. *Geophysical Research Letters*, 43: 9836-9842.
- 1840 Gangopadhyay, A., Gawarkiewicz, G., Silva, E. N. S., Monim, M., and Clark, J. 2019. An Observed Regime Shift in the Formation of Warm Core Rings from the Gulf Stream. *Scientific Reports*, 9: 12319.
- Gawarkiewicz, G., Chen, K., Forsyth, J., Bahr, F., Mercer, A. M., Ellertson, A., Fratantoni, P., et al. 2019. Characteristics of an Advective Marine Heatwave in the Middle Atlantic Bight in Early 2017. *Frontiers in Marine Science*, 6: 712.
- 1845 **Environmental impacts on squid population dynamics**
- 1850 Rodhouse, P. G. K., Pierce, G. J., Nichols, O. C., Sauer, W. H. H., Arkhipkin, A. I., Laptikhovskiy, V. V., Lipiński, M. R., et al. 2014. Chapter Two - Environmental Effects on Cephalopod Population Dynamics: Implications for Management of Fisheries. In *ADVANCES IN MARINE BIOLOGY*, pp. 99-233. Ed. by E. A. G. Vidal. Academic Press.
- 1855 Bakun, A., and Csirke, J. 1998. Environmental process and recruitment variability. In *Squid recruitment dynamics. The genus Illex as a model. The commercial Illex. Influences on variability*, pp. 105-124. Ed. by P. G. Rodhouse, E. G. Dawe, and R. K. O'Dor. , *FAO Fisheries Technical Paper 376*.
<https://www.dropbox.com/s/zsdqjqr2342clve/Bakun-Csirke-1998.pdf?dl=0>

Appendix Table 4. A summary review of shortfin squid assessments compiled by Paul Rago. See https://www.nefsc.noaa.gov/saw/reviews_report.php for assessments			
SARC #	Year	Status/MSY etc	Comments
1	1985	Status based on Lange 1984 Lab Ref Doc 84-38	<ul style="list-style-type: none"> • Stock structure & recruitment mechanisms unresolved. More basic research required. • Improved abundance indices necessary. • Surveys only cover a portion of range by latitude & depth.
2	1986	<ul style="list-style-type: none"> • Not enough information to change long term potential catch from current value of 30,000 mt • Unlikely low survey indices due to that Fishing mortality 	<ul style="list-style-type: none"> • Harvest dependent on availability & since fishery takes place in a portion of range, it is not likely that the catch in recent years adversely affects stock • NEFSC beginning to investigate effects of warm core rings.
4	1987	<ul style="list-style-type: none"> • Single age class • Fishery CPUE slightly above average • Suggested availability continuing to decline 	<ul style="list-style-type: none"> • Used CPUE (50% criterion) from US fleet • Industry suggested looking at CPUE for individual trips (by vessel) • Industry expressed concern that stock may undergo dramatic fluctuations in abundance & availability & such changes may be difficult to assess on a timely basis.
6	1988	<ul style="list-style-type: none"> • Above average abundance in survey suggested higher catches expected in 1989 • Possible effects of latitudinal variation in squid sizes discussed. 	<ul style="list-style-type: none"> • Focused on temperature effects on survey indices • Southward shift since 1980s in response to oceanography. • Lack of coherence between survey and catches in following year.
8	1989	1988 landings down by 81% from 1987, but only 1 mt from foreign fleets.	<ul style="list-style-type: none"> • Concerns raised about bias in commercial CPUE • Decline in effort in 1988 in response to market conditions • Discussions of utility of

			<p>survey indices</p> <ul style="list-style-type: none"> • Should examine temperature effects
10	1990	Current stock size should support catches ~19,500 mt	<ul style="list-style-type: none"> • Availability is associated with factors not fully understood. • Noted how catches hold at high or low levels for several years before dramatic change.
12	1991	<ul style="list-style-type: none"> • Abundance is relatively high • No evidence of over exploitation 	<ul style="list-style-type: none"> • Availability varies as much or more than abundance • Cross-over life cycle • Develop survey to estimate abundance of pelagic stocks • Identify factors affecting availability
14	1992	<ul style="list-style-type: none"> • Abundance > mid 1980's • No evidence of overexploitation 	<ul style="list-style-type: none"> • Collie-Sissenwine model using catch and fall survey • Attempted Multifan (model based on length freq analysis) • Effort standardization GLM • Discussion of availability
17	1993	<ul style="list-style-type: none"> • Medium biomass level • MSY=30,000 mt • Overfishing → pre-recruits < 1st quartile of autumn bottom trawl series. 	<ul style="list-style-type: none"> • Biomass estimates based on minimum swept area, but these were less than catches → need efficiency + availability • First recommendation for real-time management • Annual species verified • Substantial portion of <i>Illex</i> outside survey area most years. • Availability varies with environment and predation.
21	1995	<ul style="list-style-type: none"> • Fmax ~ 0.6/yr • Various YPR based models proposed using assumed M • Sensitivity to post spawning M=2M base • Discussion of escapement target of 40% MSP • Surplus production model • Expected long term yield = 25,049 mt • At F20% = 24,272 mt MSY 	<ul style="list-style-type: none"> • Surplus production model — convergence issues (22% failure rate) • Recommend increase in sampling effort in commercial landings • Improved GLM for CPUE. 25% target trips • Adjustment of survey indices day/night • Growth curve estimated (202

		<ul style="list-style-type: none"> • Median Yield at F50%=15,392 mt {10,754-23,237} 	<ul style="list-style-type: none"> • samples, max age=250 d • M=0.26-0.39/month • Realtime mgt methods proposed based on Falklands. • Suggest Leslie-Delury method
29	1999	<ul style="list-style-type: none"> • Overfishing not likely • Overfished status unknown • Current reference points may not ensure adequate spawning escapement • Unable to predict recruitment 	<ul style="list-style-type: none"> • First in-season model developed using average weights from industry. • Suggested that F was well below any YPR or SPR based reference points • In-season assessment developed • Applied Leslie Delury to estimate upper bound on F • Estimated fraction of habitat to estimate lower bound • Examined effects of delayed season on quota increase • Recommended spawning escapement as basis for Biol Reference point.
37	2003	<ul style="list-style-type: none"> • Unknown. B=?, F=? but overfishing unlikely. • No biomass targets 	<ul style="list-style-type: none"> • TAC 24,000 may not prevent overfishing. Noted declines in body weight 2000-2002 • Max age 215 days • In-season model updated to include recruitment+ natural mortality (M) revisions • M=0.01/wk; mature M=0.8/wk • Relative F computed • Notes contribution of coop research.
42	2005	<ul style="list-style-type: none"> • Unknown B • Unknown F • No reference points accepted • Advances in modeling 	<ul style="list-style-type: none"> • More sophisticated models developed. • Improved the real-time estimation • Continue cooperative research • Monitor in-season maturation

Appendix Table 5. History of industry science collaboration

- 1865 **1. Industry-Science Collaborations 1995-2019**
- 1995—Real-time management recommended at SARC 21
 - 1996—Increase sampling intensity at ports and observer coverage
 - 1997—Industry delayed start of season to allow squid to reach 100g
 - F/V Darana Illex trip for tow based data
 - 1870 • 1998—Closure of fishery at 24% above quota.
 - Acoustics workshop with Illex industry, CA and Falkland experts
 - 1999—Real-time feasibility study with 12 F/V captains (90% of total landings)
 - Used RTM CPUE and biological data in SARC 29
 - Created website for study fleet data
 - 1875 • 2000—First Industry based bottom trawl survey
 - Two F/V, with Rutgers and NEFSC scientists
 - Discovered Illex spawning grounds
 - Characterization of L50 and A50 for maturation, also growth rates, pre-fishery abundance estimate
 - 1880 • 2002—First e-VTR study fleet, real-time tracking by BOatracs, database developed
 - Discontinued due to lack of infrastructure support.
 - 2003—New weekly maturation-natural mortality model to account for semelparity
 - In-season assessment model but not considered sufficient for setting quotas or assessing stock status
 - 1885 • 2004—Illex pilot study bottom trawl survey published
 - 2006 natural mortality maturation paper published
 - SARC 42 model improved but still not considered sufficient for setting quotas or assessing stock status
 - 1890 • 2019—examination of pre-fishery abundance indicators using oceanography

Appendix Table 6

1895 **2. Some Key Considerations for Future Quota Setting—especially for In-Season Adjustments**

- “Logical” assessments
 - Establish bounds on feasible range of fishing mortality
 - Envelope model (e.g. applied to butterfish)
 - Models used in 1999, 2003, 2006
 - Swept area analyses

1900

- Metrics of fishing success, i.e., Indicators
- In the short run, it is unlikely that we will be able to estimate stock size quantitatively (Poor, Average, Good)

1905

- Linkages to environmental conditions: predictability, persistence, availability

Timing of information for science, management, business is important. Its important to reduces time delays chasing a stock that lives fast and dies young.

1910

Appendix 6: Draft Illex harvester survey

Draft Survey of Illex Squid Harvesters

1. Are you a current harvester of Illex squid?



Yes

No

2. How many years have you been fishing?

0 60

3. From your perspective, how would you rate the following fishing years?

Hide comments

	Poor	Average	Good	No firsthand knowledge of this year	
1996	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1997	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1998	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1999	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2000	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2001	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2002	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2003	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2004	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2005	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2006	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2007	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

1915

2008	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2009	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2010	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2011	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2012	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2013	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2014	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2015	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2016	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2017	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2018	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2019	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

4. What type of Illex fishing vessel do you have?




- RSW
- Freezer
- Ice or fresh boat
- Other (please specify)

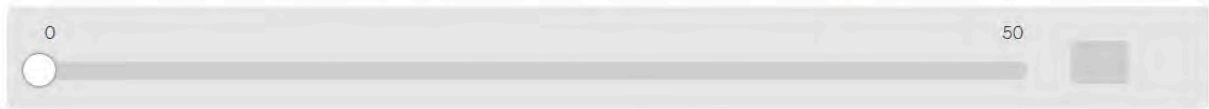
5. What limits the maximum amount of Illex catch you can harvest during a trip?




Hide comments

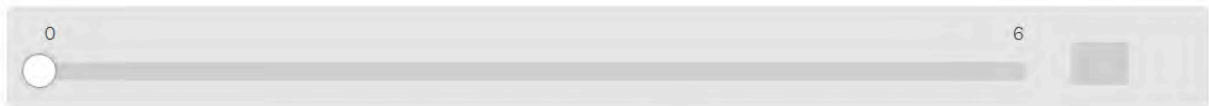
- Hold capacity
- Number of plate freezers
- Number/volume of RSW tanks
- Length of time that catch remains fresh
- Catch processing time (sorting and freezing)
- Other (please specify)

6. On average, how many tows do you make during an Illex fishing trip 




A horizontal slider control with a range from 0 to 50. The slider knob is positioned at approximately 10.

7. What is the average duration of your tows? (in hours) 



A horizontal slider control with a range from 0 to 6. The slider knob is positioned at approximately 1.5.

8. During an average trip, how many total hours do you spend conducting short test tows and searching between fishing locations for new schools of squid? 



A horizontal slider control with a range from 0 to 24. The slider knob is positioned at approximately 4.


1920

9. What do think is the best measure of fishing effort? 

- Total trip time in days (dock to dock)
- Total hours fished (time gear is on the bottom)
- Number of trips taken per season
- Total swept area of trawl gear during trip
- Other (please specify)



A horizontal text input field for specifying other measures of fishing effort.

10. What is your suggestion for the best way to measure Illex abundance? Please be as specific as possible. Possible examples: a targeted trawl survey, vessel CPUE, acoustic survey, etc. 



A horizontal text input field for providing suggestions for measuring Illex abundance.