Longfin Inshore Squid (*Doryteuthis (Amerigo) pealeii*) Stock Assessment Update for 2017

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State of Stock  
This stock assessment update for longfin inshore squid (*Doryteuthis (Amerigo) pealeii*) adds catches, population biomass, and relative exploitation indices for 2010–2016 to data included in the 2010 benchmark assessment (NEFSC 2011a). During 2016, the longfin squid stock was not overfished because the average of catchability-adjusted, swept-area biomass estimates derived from the NEFSC spring and NEFSC plus NEAMAP fall surveys during 2015-2016 (73,762 mt; 80% CL = 67,198, 80,327) was much greater than the threshold B_{MSY} proxy of 21,203 mt (Figure 1). The overfishing status could not be determined because there are no fishing mortality reference points for the stock.

Catch  
*Landings:* The U.S. squid fishery began in the late 1800s as a source of bait. From 1928 to 1967 annual squid landings (including longfin squid plus Northern shortfin squid, *Illex illecebrosus*) from Maine to North Carolina ranged from 500 to 2,000 mt (Lange and Sissenwine 1980). During 1967-1984, landings of longfin squid were predominately from an offshore international fishery and averaged 20,130 mt, with a peak of 37,613 mt in 1973 (Figure 2). A small, seasonal domestic fishery operated inshore prior to 1987 and a domestic offshore fishery developed thereafter when the international fishery was eliminated. During 1987-2015, landings averaged 15,392 mt with a peak of 23,738 mt in 1989. Landings were generally higher during 1987-1999 then gradually declined from 17,540 mt in 2000 to 6,751 mt in 2010. Landings increased thereafter to 18,379 mt in 2016 which was the highest level since 1999 and 82% of the annual quota of 22,445 mt. The 2016 landings include an estimate of 254 mt for state-permitted vessels (1.4% of the 2016 landings, which was the average percentage landed by state-permitted vessels during 2007-2015) because these data were not yet available.

The onset and duration of the fisheries reflect the timing of squid migrations; generally offshore during October-March and inshore during April-September. Landings have been affected by in-season quota management during most years since 2000, when trimester quotas were in effect during 2000 and 2007-2017 and quarterly quotas were in effect during 2001-2006. Since 2000, in-season fishery closures have occurred during every year except 2010, 2013 and 2015 (Hendrickson 2015). During 2007-2010, most of the landings were taken during Trimesters 1 or 3 but this trend shifted to Trimester 2 during most years thereafter.

*Discards:* During 1989-2015, discard estimates averaged 3.0% of the landings but were imprecise. The estimates ranged from 0.4% to 11.2% (Figure 3) and most discards occurred in the small-mesh (codend mesh size ≤ 63 mm) bottom trawl fisheries conducted in the Mid-Atlantic region (i.e., Statistical Areas > 600). CVs of the discard estimates ranged between 2%
and 114% and averaged 53% but were consistently lower (average = 30%) during 2011-2016 when small bottom trawl trips were sampled more frequently.

The 2016 discard estimate was based on a longfin squid discard weight to kept weight ratio computed with data from the Northeast Fisheries Observer Program Database, for bottom trawl trips, that was scaled up to the total longfin squid landings from the Dealer Database. This method differed from the Standard Bycatch Reporting Methodology (SBRM) that was used to estimate discards for 1989-2015 (NEFSC 2011a) because the database required to use the SBRM method was not yet available. The 2016 discard estimate was 665 mt (CV = 26%).

_Catch:_ Catches during the international fishery period, 1963-1986, averaged 17,049 mt and peaked at 38,892 mt in 1973 (Figure 3). During the domestic fishery period, 1987-2016, catches averaged 15,992 mt and peaked at 24,566 mt in 1994. During the trimester-based management period, 2007-2016, catches averaged 11,816 mt and peaked at 19,044 mt in 2016. The catch in 2016 was 81% of the ABC of 23,400 mt and was the highest catch since 1999.

_Catch and Status Table: Longfin inshore squid (weight in 000s mt and arithmetic means)_

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
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<tbody>
<tr>
<td>Landings</td>
<td>12.3</td>
<td>11.4</td>
<td>9.3</td>
<td>6.7</td>
<td>9.5</td>
<td>12.8</td>
<td>11.2</td>
<td>12.0</td>
<td>11.9</td>
<td>18.3</td>
<td>23.5</td>
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<tr>
<td>Discards</td>
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<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.7</td>
<td>2.1</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Catch</td>
<td>12.4</td>
<td>11.5</td>
<td>9.5</td>
<td>6.8</td>
<td>9.7</td>
<td>13.1</td>
<td>11.4</td>
<td>12.2</td>
<td>12.0</td>
<td>19.0</td>
<td>24.6</td>
<td>6.8</td>
<td>16.0</td>
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<td>19.0</td>
<td>18.7</td>
<td>19.9</td>
<td>22.2</td>
<td>22.0</td>
<td>22.0</td>
<td>22.4</td>
<td>22.4</td>
<td>44.0</td>
<td>15.0</td>
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<td>72.0</td>
<td>54.4</td>
<td>61.3</td>
<td>62.9</td>
<td>94.0</td>
<td>109.6</td>
<td>NA</td>
<td>NA</td>
<td>73.8</td>
<td>141.0</td>
<td>34.5</td>
<td>81.5</td>
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<tr>
<td>Exploitation Indices</td>
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<td>0.18</td>
<td>0.11</td>
<td>0.16</td>
<td>0.14</td>
<td>0.10</td>
<td>NA</td>
<td>NA</td>
<td>0.26</td>
<td>0.42</td>
<td>0.10</td>
<td>0.22</td>
</tr>
</tbody>
</table>

1: During 1987-2016 quotas in effect were annual (1987-1999); trimesters (2000 and 2007-2016); and quarterly (2001-2006)
2: Dead discards
3: Two-year moving average of the mean biomass estimated from NEFSC and NEAMAP fall bottom trawl surveys and NEFSC spring surveys. NA indicates that biomass could not be estimated due to incomplete sampling coverage of longfin squid habitat during the 2014 NEFSC spring survey.
4: Catch divided by population biomass. N indicates that the exploitation index could not be estimated due to incomplete sampling coverage of longfin squid habitat during the 2014 NEFSC spring survey.

**Projections**

Stock size projections were not possible because there is no accepted population dynamics model for projection calculations.

**Stock Distribution and Identification**

Longfin squid are distributed in continental shelf waters located between Newfoundland and the Gulf of Venezuela (Cohen 1976; Dawe et al. 1990). In the Northwest Atlantic Ocean, longfin squid are most abundant between Georges Bank and Cape Hatteras, North Carolina. Longfin
squid are found in the Gulf of Maine during May-October and are less abundant there during May. The species undergoes annual seasonal migrations which are influenced by environmental conditions (Dawe et al. 2007). Migrations are south and offshore near the shelf edge during late fall through winter (generally October-March) and north and inshore during spring through early fall (generally April-September). Distribution and abundance of longfin squid south of Cape Hatteras is uncertain because the species’ range overlaps with the congener, *D. pleii*, throughout the year and the two species cannot be distinguished using gross morphology (Cohen 1976). The Northwest Atlantic population of longfin squid is managed as a single stock based on the results of genetics studies conducted on squid samples collected between Cape Cod Bay and the Gulf of Mexico (Arkhipkin et al. 2015).

**Data and Assessment**

Details of the assessment methods are described in NEFSC (2011a). The stock was assessed based on catchability-adjusted swept-area biomass computed using daytime tows from Northeast Fisheries Science Center (NEFSC) spring (March-April), NEFSC fall (September-October) and Northeast Area Monitoring and Assessment Program (NEAMAP) fall (September) bottom trawl surveys. Only daytime catches were used to compute the biomass estimates because the capture efficiency of bottom trawls is highest for longfin squid during the day (Sissenwine and Bowman 1976; Brodziak and Hendrickson 1999). Catches were updated for 2010-2016 with discards and landings. Seasonal and annual relative exploitation indices, computed as catch divided by survey biomass, were also updated for 2010-2016. Biomass estimates for NEAMAP fall surveys during 2009-2016 were added to the biomass estimates derived from the NEFSC fall surveys, assuming no migration between the two survey areas during September. Sampling during NEAMAP surveys covers the two shallowest inshore strata sets (primarily ≤18m and between Block Island Sound and Cape Hatteras, NC) that were sampled during NEFSC surveys prior to 2009 but that can no longer be sampled because the current NEFSC survey vessel (SRV *H.B. Bigelow*) cannot sample these shallow depths. Biomass estimates from the spring NEAMAP surveys, which occur primarily in May, were not used in the stock assessment because longfin squid distribution maps from NEFSC spring surveys suggest that sampling of squid in May would result in the double-counting of squid that were previously sampled during March-April in the NEFSC spring surveys.

Biomass estimates for 1976-2009 were updated with data for 2010-2016. Following NEFSC (2011a), catchability (*q*) was estimated as the median of the prior distribution which was computed using upper and lower bounds on effective tow distance, width of the area swept by the gear, capture efficiency and stock area. Catchability estimates may be greater than 1.0 because their estimation included a multiplier to convert stratified mean kg per tow indices to thousands of metric tons. Biomass indices for NEFSC spring and fall surveys conducted during 2009-2016 were converted from FSV *H.B. Bigelow* units to R/V *Albatross* units by applying spring and fall conversion factors (Miller et al. 2010). There is no conversion factor to standardize the 2009-2016 stratified mean kg per tow indices from the NEAMAP fall surveys to R/V *Albatross* units. Therefore, the median *q*-prior (= 1.894) was computed using values specific to the fall NEAMAP surveys. In particular, the upper and lower bounds on effective tow distance were 1.85-1.86 km, respectively. The lower bound for the width of the area swept by the gear was the average wingspread during 2007-2016 (= 0.0134 km) and the upper bound was the
average door spread (= 0.0323 km). The bounds for capture efficiency were 0.20 and 0.95 and the stock area was the area of the fall survey longfin squid strata set (= 12,097 km²).

The spring and fall biomass estimates represent average biomass estimates of the seasonal cohorts available to the January-June and July-December fisheries, respectively. Relative exploitation indices for the two fisheries were computed on a seasonal basis, for 1987-2016, as January-June catch/March-April biomass and July-December catch/September-October biomass.

Stock status was determined based on the 2015-2016 average of the spring and fall biomass. Annual exploitation indices were computed as the 2015-2016 mean of the average of the NEFSC spring and fall survey biomass.

**Biological Reference Points**

The existing biological reference points for longfin squid were derived in 2010 during SAW 51 and assumed the stock was lightly exploited during 1976-2008 (NEFSC 2011a). The median of the average biomass for the NEFSC spring and fall surveys during 1976-2008 (76,329 mt) was assumed to represent 90% of the stock’s carrying capacity ($K$; see Special Comments) and the $B_{MSY}$ proxy (42,405 mt) was estimated as 50% of $K$ (i.e., 0.50*(76,329/0.90)). The biomass threshold is 21,203 mt, which is 50% of $B_{MSY}$.

Fishing mortality reference points could not be recommended in the 2010 assessment due to the lack of evidence that annual catches impacted annual biomass estimates during 1976-2009 (Figure 1) and due to the lack of a theoretical basis for linking $F_{MSY}$ to natural mortality or $F_{%SPR}$ from per-recruit models for short-lived species like longfin squid. The stock is believed to be lightly exploited because annual catches during 1987-2016 were less than annual biomass and did not result in a multi-year decrease in biomass. In addition, estimates of natural mortality for this semelparous species were very high in relation to exploitation indices.

**Exploitation indices**

Annual exploitation indices (catch in year $t$ / average of biomass in year $t$ and $t$-1) were generally higher and above the median during 1987-1998 than during 1999-2016 (Figure 3A). The 2016 relative exploitation index (2016 catch/average of the NEFSC spring and NEFSC plus NEAMAP fall survey biomass during 2015-2016) of 0.258 was 45% greater than the 1987-2015 median (0.178). Exploitation indices for the two seasonal cohorts caught in the NEFSC spring and NEFSC and NEAMAP fall surveys were higher for the January–June fishery (Figure 3B) than for the July-December fishery (Figure 3C), respectively. The January-June exploitation indices were generally near the median during 2007-2011 and were below the median during 2012-2013 and in 2016. The July-December exploitation indices have been gradually increasing since 2006 and were near the median in 2016.

**Recruitment**

Given the sub-annual lifespan, complex life history characteristics of the species (refer to Special Comments section) and the lack of a suitable assessment model, recruitment could not be estimated.
Biomass
Squid species exhibit large inter-annual fluctuations in biomass (Boyle and Rodhouse 2005). During 1976-2016, annual biomass (the average of NEFSC spring and NEFSC and NEAMAP fall survey biomass) ranged between 25,806 mt and 175,894 mt (Figure 1). The average of annual biomass during 2015-2016 was 73,762 mt (80% CL = 67,198, 80,327) and was much greater than the threshold BMSY proxy of 21,203 mt and the target BMSY proxy of 42,205 mt (Figure 1).

During 1976-2015, spring survey biomass levels (median = 23,714 mt; Figure 4A) were only one fifth of the fall survey biomass levels (median = 124,999 mt; Figure 4B), suggesting that the productivity of the spring survey cohort may be much lower than the fall survey cohort. Catches during January-June were also higher than the catches during July-December and were similar to or greater than the spring biomass estimates during some years.

Ecosystem considerations
This semelparous, subannual species is consumed by a wide range of cetacean, pinniped, avian, invertebrate and finfish predators. Natural mortality (M) is very high; especially for spawners; 0.19-0.48 per week during spawning when non-spawning M was fixed at 0.11 per week (NEFSC 2011a).

Special Comments
Recruitment occurs throughout the year with seasonal peaks in overlapping “microcohorts” which have rapid and different growth rates (Brodziak and Macy 1996; Macy and Brodziak 2001). Annual biomass estimates for longfin squid exceed annual carrying capacity in multiple years, which is to be expected for a species with highly variable seasonal population dynamics that are linked to variability in environmental conditions (Arkhipkin et al. 2015). The average lifespan of each seasonal cohort is about six months. Age data indicate that longfin squid caught in the offshore winter fishery (October-March) were hatched about six months prior, during the previous summer, and squid caught in the inshore summer fishery (April-September) were also hatched about six months prior, during the previous winter (Macy and Brodziak 2001). The NEFSC spring (March) and fall (September-October) surveys are conducted six months apart. Relative abundance of the two seasonal cohorts caught during the spring and fall surveys in the same year, during 1976-2009, were significantly correlated. However, relative abundance in year \( t \) and year \( t+1 \), for either survey, or between the fall surveys in year \( t \) and spring surveys in year \( t+1 \) were not correlated (NEFSC 2011a).

Female longfin squid attach their egg masses to the seabed, vegetation and fixed objects (Jacobson 2005) and can lay multiple clutches of eggs during a period of up to three weeks (Maxwell et al. 1998; Maxwell and Hanlon 2000). Incidental catches of the species’ egg masses in the inshore bottom trawl fishery for longfin squid (Hatfield and Cadrin 2002), indicate that the fishery occurs on the inshore spawning grounds. The impacts of dislodging the negatively buoyant egg masses from the seabed during bottom trawling are unknown, but mechanical disturbance of the egg masses during the late stages of development causes premature hatching that is fatal to all hatchlings because of incomplete absorption of the outer yolk sac (Hanlon 1990; Boletsky and Hanlon 1983; Vidal et al. 2002; Vidal 2014). Age data indicate that longfin squid spawn throughout the year (Brodziak and Macy 1996; Macy and Brodziak 2001). However, the inshore fishery occurs on the only known spawning grounds and it is unknown what portion of annual
egg production is attributable to the inshore spawning period. During the inshore fishery, squid are highly aggregated because of their complex mating and communal spawning behaviors (Hanlon 1998; Shashar and Hanlon 2013), but the effects of bottom trawling on these behaviors is unknown.

Because of the species’ sub-annual lifespan, semelparous life history, and highly variable recruitment, management of longfin squid based on either a fixed TAC or effort is likely to result in foregone yield during periods of high productivity and may not protect the resource during periods of low productivity. For squid species, adequate spawner escapement from each seasonal fishery is required to ensure sufficient recruitment in subsequent seasons, and in–season assessment and management are necessary to harvest the resource at optimum yield. Because squid stocks are susceptible to recruitment overfishing, other squid stock assessments (Pacific Fishery Management Council 2002; NEFSC 2003) have considered F%SPR reference points to ensure adequate spawner escapement.

Longfin squid biomass estimates derived from NEFSC spring and fall surveys conducted in the same year correspond to two different seasonal cohorts, both of which show a high degree of interannual variability. As a result this variability, the overfished status of longfin squid was determined using a two-year moving average of the mean biomass of the NEFSC spring and NEFSC plus NEAMAP fall surveys.

References


Figure 1. Annual estimates of longfin squid biomass (average of annual biomass during NEFSC spring and NEFSC plus NEAMAP fall surveys) in relation to biomass reference points and catches. The grey line represents the two-year moving average.

Figure 2. Landings, discards and catches (000’s mt) of longfin squid during 1963-2016 and TACs during 1976-2017. The horizontal dashed line is the 1987-2015 average catch for the USA bottom trawl fishery.
Figure 3. Annual exploitation indices (annual catch/average of the annual spring and fall survey biomass) for longfin squid (A), seasonal exploitation indices for the January-June fishery (January-June catch/March-April biomass for NEFSC spring surveys) (B) and the July-December fishery (July-December catch/September-October biomass for NEFSC and NEAMAP fall surveys; (C)). The grey line represents the catch in year $t$ divided by the two-year moving average of biomass.
Figure 4. Longfin squid biomass estimates from NEFSC March-April surveys in relation to January-June catches (A) and biomass indices from NEFSC and NEAMAP (2009-2016) September-October surveys in relation to July-December catches (B). The grey lines represent the two-year moving averages.