22. Assessment of the Octopus Stock Complex in the Gulf of Alaska

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Executive Summary

The Gulf of Alaska (GOA) octopus complex is assessed on a biennial stock assessment schedule with full assessments provided in odd years. In even years we present an executive summary to recommend harvest levels for the next two years. The last full assessment was conducted in 2015 (Conners *et al*. 2015, http://www.afsc.noaa.gov/REFM/Docs/2015/GOAocto.pdf).

Through 2010, octopuses were managed as part of the "other species" complex, with catch reported only in the aggregate along with sharks, squids, and sculpins. Due to increasing market interest, retention of some members of the other species complex members increased. In 2011, the GOA Fishery Management Plan was amended to provide separate management for sharks, sculpins, and octopus. In compliance with the reauthorized Magnuson-Stevens Act, each group has its own annual catch limit. Catch limits for octopus for 2011-2014 were set based on the average of the last 3 surveys as a minimum biomass estimate. For 2015-2017 the random effects model applied to survey biomass estimates is used to provide a minimum biomass estimate.

For management purposes, all octopus species are grouped into a single assemblage. At least seven species of octopus are found in the GOA. Octopuses are taken as incidental catch in trawl, longline, and pot fisheries throughout the GOA; a portion of the catch is retained or sold for human consumption or bait. The highest octopus catch rates are from Pacific cod pot fisheries in the central and western GOA (NMFS statistical areas 610 and 630).

In general, the state of knowledge about octopus in the GOA is poor. A number of research studies and special projects have been initiated in recent years to increase knowledge for this assemblage; results of these studies are summarized in Appendix A1.

Summary of Changes in Data

There was no GOA survey in 2016. Catch data for 2015 and for 2016 through October 28, 2016 have been added to this summary.

Summary of Changes in Assessment Methods

There have been no changes in the assessment methods. This is a Tier 6 assessment with an alternative method approved by the Plan Team and SSC. A minimum biomass estimate based on trawl survey data and a conservative rate of natural mortality are used to set OFL and ABC, as in previous years.

Summary of Results

The most recent data available are from the 2015 GOA trawl survey. For estimation of minimum biomass, the GOA survey biomass time series was run through the random effects smoothing model developed by the Plan Team Survey Averaging Work Group. The 2015 biomass estimated by this model was used as the minimum biomass estimate in 2015 for the 2016 ABC, and is proposed for the 2016 minimum biomass estimate for the 2017 ABC. As a result, the recommended catch limits are unchanged from 2015.

Since catches have remained below OFL, this complex has not been overfished. There is insufficient data to determine whether the complex is being subjected to overfishing or is approaching a condition of being overfished.

Summary of Harvest Recommendations

Quantity	As estimated or *specified last* year for: 2016	2017	As estimated or *recommended this* year for: 2017	2018
Tier 6 (model biomass * *M*)	6(alt)	6(alt)	6(alt)	6(alt)
OFL (t)	6,504	6,504	6,504	6,504
maxABC (t)	4,878	4,878	4,878	4,878
ABC (t)	6(alt)	6(alt)	4,878	4,878
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	n/a	n/a	n/a	n/a

Responses to SSC and Plan Team Comments on Assessments in General

Meetings of the Plan Teams in September 2015 and the SSC in December 2015 and October 2016 had no general comments that apply to this off-year summary.

Responses to SSC and Plan Team Comments Specific to this Assessment

At their December 2015 meeting, the SSC had the following comments:
"The SSC recommends that estimation of octopus natural mortality be added to its research priorities list."
A further review of recent research and literature on natural mortality rates for cephalopods will be included in the next full assessment.

At their October 2016 meeting, the SSC discussed recent research results presented to the Joint Plan Teams. These research results are included as appendix A1. The teams were also presented with preliminary results for a theoretical octopus population model; a description of the model is presented in Appendix A2.

Data

Fishery

Incidental Catch Data

From 1997-2001, total incidental catch of octopus in state and federal waters was generally between 100 and 200 t, with a peak of 298 t in 2002 (Table 1). Catches in 2007-2010 were somewhat higher; between 250 and 350 t. From 2011 through 2015 catches of octopus in the GOA increased substantially, with catches over 900 t in 2011, 2014, and 2015. **The catch through October 22, 2016 has been much lower, at only 301 t.** In general, the amount of catch retained has been in the range of 200-300 t since 2003, but 530 t was retained in 2014. In 2016, 48.5% of the catch, or 146 t, was retained. As in previous years, the majority of the catch came from Pacific cod fisheries in areas 610 (Shumagin) and 630 (Kodiak).

Survey

High rates of incidental catches in 2002, 2004, 2009, 2011, and 2014-15 correspond to high survey catches in 2003, 2009, 2011, and 2015 (Table 2, Figure 1). The 2015 survey biomass estimate for the GOA was the highest ever observed, at 12,990 t. The percentage of hauls in the survey containing octopus was also at a record high in 2015, and shows an increasing trend from 2009-2015.

Results

Harvest Recommendations

None of the existing groundfish Tier strategies are well suited to the available information for octopus. We recommend that octopus be managed very conservatively due to the poor state of knowledge of the species composition, life history, distribution, and abundance of octopus in the GOA.

Trawl survey estimates of biomass for the species complex represent the best available data at this time. There are serious concerns, however, about both the suitability of trawl gear for accurately sampling octopus biomass and the extent to which the survey catch represents the population subject to commercial harvest. If future management of the octopus complex under Tier 5 is envisioned, then dedicated field experiments are needed to obtain both a more realistic estimate of octopus biomass available to the fishery, and a more accurate estimate of natural mortality rates.

For the last few years, the GOA Plan Team has elected to use a modified Tier 6 approach, which uses a minimum biomass estimate and a natural mortality rate as is used for Tier 5 to calculate ABC and OFL. The random effects smoothing model applied to the full survey time series (Figure 2) gives a predicted biomass for the most recent year (2015) of 12,271 t. **Using the model results as the minimum biomass estimate with a natural mortality rate of 0.53, the OFL is 6,504 t and the ABC is 4,878 t.**

Because of the overall lack of biological data and the large uncertainty in abundance estimates, we do not recommend a directed fishery for octopus in federal waters at this time. We anticipate that octopus harvest in federal waters of the GOA will continue to be largely an issue of incidental catch in existing groundfish fisheries. If interest in a directed octopus fishery increases, we recommend using an experimental fishery to obtain depletion-based regional biomass estimates and to develop an octopus-specific index survey using habitat pot gear.

Table 1. Estimated catch (t) of octopus (all species) in state and federal fisheries and approximate percentage of catch retained. Catch for 1997-2002 was estimated from blend data. Catches for 2003-2016 are from Alaska Regional Office Catch Accounting System.

	Statistical Reporting Areas					GOA		
	610	620	630	640	650	Total	Retained	% Ret
1997						232		
1998						112		
1999						166		
2000						156		
2001						88		
2002						298		
2003	149	13	48	0.3	2.0	212	44	20.7%
2004	200	6	76	0.1	0.5	283	161	56.9%
2005	58	3	88		0.0	149	102	68.5%
2006	37	9	119	0.3	0.2	166	144	86.4%
2007	64	22	179	0.0	0.1	266	239	89.8%
2008	125	28	186		0.1	339	278	82.0%
2009	141	33	146	0.2	0.3	321	267	83.3%
2010	142	49	139	0.2	0.1	330	272	82.2%
2011	565	92	268	0.8	1.9	927	387	41.7%
2012	177	25	212	0.1	0.0	415	275	66.3%
2013	239	29	142	17.1	14.8	442	215	48.8%
2014	494	170	627	3.5	3.0	1298	530	40.8%
2015	215	366	384	1.0	2.0	968	323	37.1%
2016*	123	69	108	0	0	301	146	48.5%

*Data for 2016 are as of October 22, 2016.

Table 2. Biomass estimates (t) for octopus (all species combined) from GOA bottom trawl surveys.

Survey Year	Survey Hauls	Hauls with Octopus Num	%	Estimated Biomass (t)	STD Err of Biomass (t)
1984	929	89	9.6%	1,498	347
1987	783	35	4.5%	2,221	959
1990	708	34	4.8%	1,029	393
1993	775	43	5.5%	1,335	422
1996	807	34	4.2%	1,960	892
1999	764	47	6.2%	994	279
2001	489	29	5.9%	994	365
2003	809	70	8.7%	3,767	810
2005	837	58	6.9%	1,125	362
2007	816	73	8.9%	2,314	503
2009	823	81	9.8%	3,791	724
2011	670	67	10.0%	4,897	894
2013	548	67	12.2%	2,686	496
2015	**772**	**119**	**15.4%**	**12,990**	**1,849**

Figure 1. GOA octopus survey biomass estimates and approximate 95% confidence intervals.

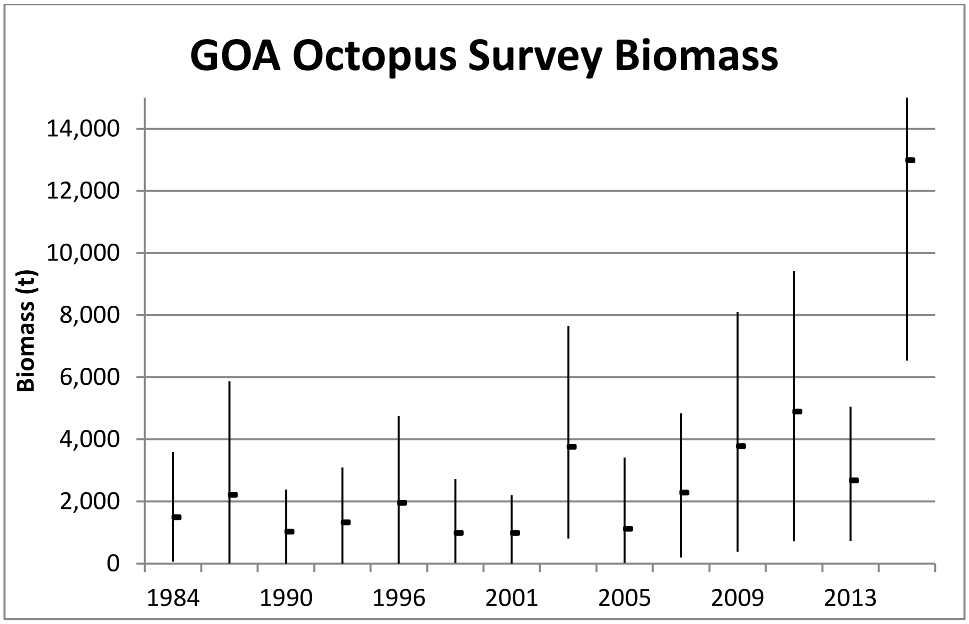
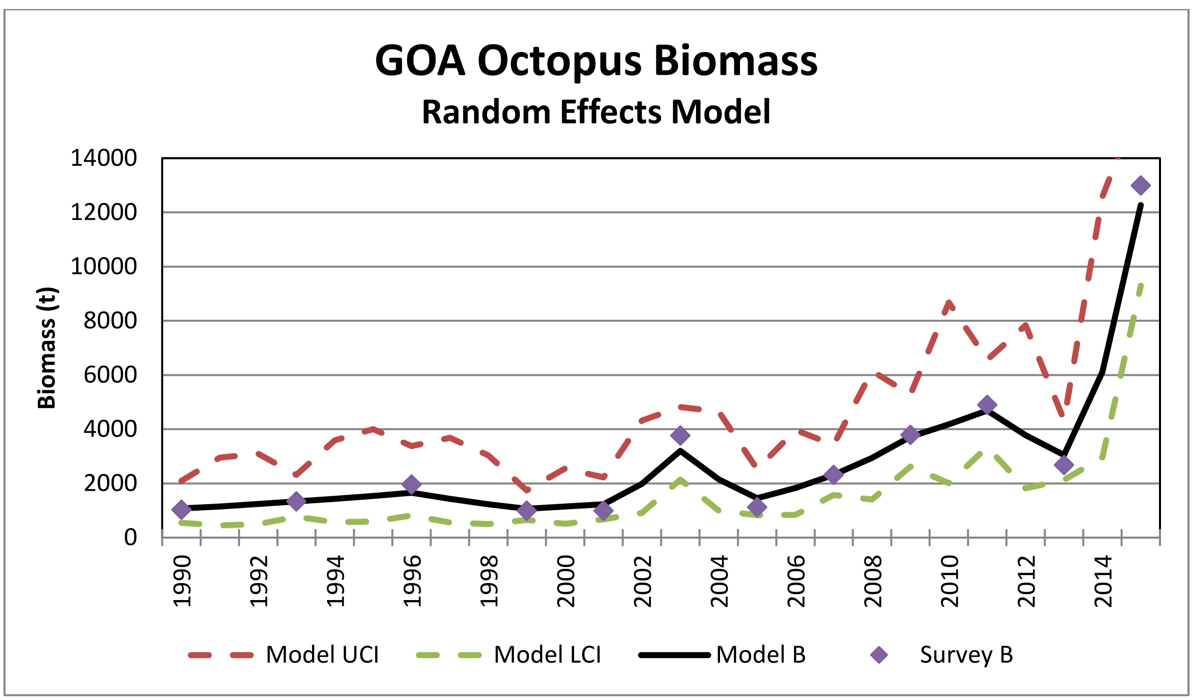


Figure 2. Random effects model results for GOA octopus survey biomass. Solid line shows model estimates of biomass, dashed lines show 90% confidence interval for the model estimates, markers show individual survey biomass estimates.



Appendix 22.A1. Summary of Octopus Research

A number of research projects have been completed in the last 5-7 years and are published or nearing publication. Areas of research, publications, and major results are summarized below.

Reproductive Cycle and Life History of E. dofleini

GOA: NPRB Project 906 included development of maturity indices for *E. dofleini* and collection of octopus specimens for dissection.

- Sexually mature octopus of both sexes were present in all seasons, suggesting spawning is not fully synchronous for this species in the GOA. The Gonadosomatic Index (GSI) of females was highest in late winter to early spring, however, suggesting a high proportion of egg laying in early spring.
- In the Gulf of Alaska, this species was found to mature between 10-20 kg with size at 50% maturity values of 13.7 kg (95% CI = 12.5-15.5 kg) for females and 14.5 kg (95% CI = 12.5-16.3 kg) for males. Size at maturity was highly variable for this species, particularly for male octopus.
- Fecundity for this species in the Gulf of Alaska was found to range from 41,600 to 239,000 eggs/female with an average fecundity of 106,800 eggs/female. Fecundity was significantly and positively related to the weight of the female (n = 33, P < 0.001).

Conners, M. E., C. L. Conrath, and R. Brewer. 2012. Field studies in support of stock assessment for the giant Pacific octopus *Enteroctopus dofleini*. NPRB Project 906 Final Report. North Pacific Research Board, Anchorage, AK.

Conrath, C.A. and M.E. Conners. 2014. Aspects of the reproductive biology of the giant Pacific octopus (*Enteroctopus dofleini*) in the Gulf of Alaska. Fishery Bulletin, U.S. 112(4):253-260.

BSAI: NPRB Projects 906 and 1005 also included collection of octopus specimens and examination of gonad maturity.

- In the southern Bering Sea, *E. dofleini* were reproductively active in the fall with peak denning occurring in the winter to early spring months.
- *E. dofleini* in the Bering Sea were found to have size at 50% maturity values of 12.8 kg for females and 10.8 kg for males. Animals smaller than 10 kg tended to be immature, but male and female octopus in the size range between 10 – 20 kg were found to be immature, maturing, and mature.

Brewer, R.S. and B.L. Norcross. (in Review) 2016. Seasonal changes in the sexual maturity and body condition of the North Pacific giant octopus (*Enteroctopus dofleini*).

Brewer, R.S. 2016. Population biology and ecology of the North Pacific Giant Octopus in the eastern Bering Sea. PhD thesis, Univ. Alaska Fairbanks.

Octopus Tagging Study

Reid S. Brewer conducted a three-year, five season tagging study on Giant Pacific Octopus captured with commercial cod pots. The study was conducted in a 25 km^2 area north of Unalaska Island in depths ranging from 50 to 200 m. A total of 1,714 *E. dofleini* were tagged and 246 were recaptured. While most of the recaptures occurred within a few weeks after tagging (same season), 32 octopus were recaptured between seasons after 60 days. Cormack-Jolly-Seber models were used to estimate survival and study-area abundance for *E. dofleini* in the size range vulnerable to commercial pot bycatch.

- The tagging method using Visual Implant Elastomers (VIE tags) was feasible. Tags were readily visible in recaptured animals and had no associated tissue damage
- In autumn when temperatures were warmest, *E. dofleini* had higher growth rates, moved more and both sexes were predominantly mature when compared to colder winter months.
- Size and water temperature also played a role in growth of tagged *E. dofleini*. The mean specific growth rate (SGR) for short-term recaptures was 0.75% d-1 ± 0.09; SGR was positively related to temperature and negatively related to size at initial capture. The mean SGR for long-term recaptures was 0.20% d-1 ± 0.03 and SGR was negatively related to size at initial capture
- Average annual survival rate of tagged octopus was estimated at 3.33% ± 2.69 SE. The survival for this population was modeled using recaptures of mostly mature individuals. Female survival estimates were lower than male survival due to sex-specific post-spawning reproductive activities.
- The abundance estimate for octopus in the study area was 3,180 octopus or 127 octopus per km^2. If this density is applied the three statistical areas in the southeast Bering Sea where most of the incident catch occurs (areas 509, 517, and 519) the estimate for octopus abundance in the 3,500 km^2 area was 1.47 million octopus.
- Mean size of octopus captured in this study was 14.1 kg, the estimated biomass estimate of octopus in the study area was 44.8 t and in the three statistical areas was 20,697 t, an order of magnitude larger than the current biomass estimate for the entire EBS.

Brewer, R.S. and B.L. Norcross. 2012. Long-term retention of internal elastomer tags in a wild population of North Pacific giant octopus (*Enteroctopus dofleini*), Fisheries Research 134-136: 17-20.

Brewer, R.S. 2016. Population biology and ecology of the North Pacific Giant Octopus in the eastern Bering Sea. PhD thesis, Univ. Alaska Fairbanks.

Brewer, R.S. and B.L. Norcross. (in Review) 2016. Seasonal changes in the sexual maturity and body condition of the North Pacific giant octopus (*Enteroctopus dofleini*).

Brewer, R.S., B.L. Norcross, and E. Chenoweth (in press). Temperature and size-dependent growth and movement of the North Pacific giant octopus (*Enteroctopus dofleini*) in the Bering Sea. Marine Biology Research

Species of Octopus Bycatch

A NOAA Cooperative Research Program project was conducted in 2006 and 2007 by AFSC scientist Elaina Jorgensen. Species identification of 282 animals at Harbor Crown Seafoods in Dutch Harbor and 102 animals at Alaska Pacific Seafoods in Kodiak confirmed that all individuals were *E. dofleini*. All plant deliveries of octopus were from pot fishing vessels.

Octopus Discard Mortality

In 2006-2007 and 2010-2012, some fishery observers collected data for a special project on octopus size frequency and condition at discard. Data from this project allowed qualitative comparisons of size frequency by gear type and the immediate capture mortality of octopus from different gear types. Two follow-up studies were conducted to examine short-term and long-term delayed mortality for octopus captured with commercial pot gear.

- The size frequency of octopus taken by different fishing gears was very distinct, with pot gear capturing almost exclusively large octopus (>10kg). Pelagic trawl and longline gear captured mostly small octopus (<2 kg), and bottom trawl gear captured a range of sizes. Patterns in size distribution for the different gear types were similar for all three ecosystems (EBS, GOA, and AI).
- Pot gear in all regions caught a much higher proportion of males than trawl and longline gears. There was also seasonal difference in sex ratios in both the EBS and GOA, with a higher proportion of males caught during the fall fishing season than during the winter. Males were generally slightly larger than females.
- Initial condition at capture was best in pot gear, with over 90% of octopus discarded from pot vessels alive in excellent condition. Octopus taken in trawl gear had the highest immediate mortality rate, with 68-94% dead or injured at discard.
- Octopus captured during Pacific cod fishing in the southeast Bering Sea in winter 2013 were held for 24 to 60 hours in circulating seawater tanks. Octopus captured ranged in size from 5.5 kg to 22.0 kg. Of the 36 octopus held, none showed any delayed mortality or decline in condition. Statistical power analysis showed that the probability of the observed result of no mortality out of 36 trials would be very small ($p < 0.05$) unless the true underlying mortality rate was larger than 8%.
- Separate long-term delayed mortality studies collected octopus on commercial pot vessels in Kodiak, Alaska and held individuals for 21 days in a running seawater laboratory. This study showed no long-term delayed mortality of uninjured octopus, and a 50% delayed mortality rate for visibly injured octopus.
- The current catch accounting for octopus assumes 100% mortality for all catch, but studies show that the discard mortality rates for octopus from pot gear are much lower. The studies discussed above provide quantitative estimates of immediate and delayed mortality rates that could be used to conduct gear-specific accounting of octopus discard mortality.

Conners, M. E. and M. Levine. 2016 (in press). Characteristics and discard mortality of octopus bycatch in Alaska groundfish fisheries. Fishery Bulletin

Conrath, C.A. and N. B. Sisson. 2016 (in press). Delayed discard mortality of the giant Pacific octopus in pot fisheries in the Gulf of Alaska. Fishery Bulletin

Habitat Pot Gear for Directed Octopus Survey & Research

NPRB Project 906 and an NMFS Cooperative Research Project included testing and developing a specialized gear for octopus fishing. The gear consists of small “habitat pots” that act as artificial den space for octopus. A large number of these pots can be longlined as a clip-on gear.

- A variety of pot designs and materials were tested for use in Alaska. In the NPRB study, plywood box pots and scrap ATV tires captured octopus much more effectively than pots made of various plastic materials. One vessel in the CR study also caught octopus using plastic pots purchased from Korea, at similar rates to plywood box pots.
- Bycatch of crabs and other species in plywood box pots was close to zero. Starfish were occasionally seen.
- Habitat pots were successfully deployed on longlines fished as tub gear, off a longline reel, and using a commercial crab hauling block. Experimentation is still needed to determine optimal pot spacing and soak times
- Octopus captured in habitat pots ranged in size from smaller than 2 kg to over 20 kg, giving a broader and more consistent size distribution than fishing and survey gears.
- Overall capture rates varied widely between seasons and locations, ranging from less than ten percent to over 50% occupancy. More development is needed to determine most productive places and seasons for fishing.
- The gear is suitable for comparative scientific studies and may be suitable for index surveys at fixed locations. Suitability of the habitat pot gear for directed commercial fishing will depend on ex-vessel prices and catch rates.

Age Determination in Giant Pacific Octopus

Collections of octopus beaks, stylets and statoliths were made during NPRB projects and from AFSC surveys. Preliminary analyses have been conducted, but a funded research project would be needed to determine if accurate methods for age determination can be developed.

- Hood length of both upper and lower octopus beaks is strongly correlated with octopus weight and can be measured on beaks in stomach contents.
- Statoliths of *E. dofleini* are too soft and chalky for age reading, but beaks and stylets both show banding patterns in cross section that may be correlated with age.
- Translating beak or statolith bands to age will require a validation study using octopus marked with radioisotopes or chemicals and held for known time periods.

Appendix 22.A2. Theoretical Octopus Population Model

General Model Formulation

The base model is a stage-based model based on total weight and reproductive status of the octopus. Computer code is designed to allow the number of stages and the size range of each stage to be changed as needed. Initial inputs include the number of stages and the average weight of each stage. The final stage always represents reproductive adults: sexually mature animals that will mate, lay eggs, and die within the next time step. The remaining stages represent various sizes of immature animals. The model is not age-based because there is as yet no established method for aging *E. dofleini*. If the growth parameters are set so that each immature stage grows to the next size stage in each time step, with none remaining in the current stage, then the stage model is identical to an age-based model. There is an additional important life stage that is not explicitly included in the model. The planktonic paralarval stage is not modeled, but is considered to be a major source of early natural mortality and recruitment variability. The first size stage of the model represents small octopus after they have settled from the paralarvae to a fully benthic habitat, approximately one year after mating of mature octopus.

The transition matrix for the model is determined by parameters for growth and maturation. In this formulation, the survivors of each immature size stage are presumed to either grow to the next size stage, stay in the same size stage, or mature into reproductive adults. Immature octopus were assumed to not grow more than one size stage in each time step, and individual weight loss to a smaller size step was assumed not to occur. The larger size stages may also mature into reproductive adults (stage 6). The transition probabilities, conditioned on survival, are thus made up of three input vectors: the probability of staying in the same size range (g0, failing to grow enough to reach the next stage), the probability of maturing into reproductive adults (mat), and the probability of growing to the next size class (g1). This last vector is calculated to ensure that the conditional transition probabilities sum to one. The transition matrix (conditional probability of growth or maturity given survival) has the vector g0 along the diagonal, g1 above the diagonal, and mat in the final column.

The mortality matrix is composed of natural mortality and the sum of any fishery and survey mortalities. Natural mortality is a parameter that is input as a vector of stage-based natural mortalities. The natural mortality for the reproductive adult stage is set high to produce 100% post-spawning mortality of this size class. Fishery mortality from each source is the product of an overall fishing rate (*Ff*) and a vector representing size selectivity for the fishery for each size stage. The overall fishing rate is assumed to be proportional to abundance, with an unknown capture efficiency (*q*). Total mortality is calculated as the sum of natural and fishery mortality. Numbers of individuals in the successive time step is the product of instantaneous mortality and the conditional transition probabilities.

Recruitment is initially assumed constant, then is treated as a random variable with a mean recruitment level and recruitment variance as input parameters. There is also an option to use a general Beverton-Holt stock-recruitment function to model recruitment by specifying steepness as an input parameter. The random model is probably most representative of recruitment in *E. dofleini*; the population is largely unfished and there is strong and interannually variable mortality in the planktonic paralarval stage. Given the high fecundity of *E. dofleini* (90,000 eggs/female in the GOA, Conrath and Conners 2014) effects of reduced spawning biomass on recruitment are not likely to be seen unless fishing pressure is extremely heavy.

The model simulates population dynamics from input parameters and starting conditions. As with any steady-stage model, if parameters are constant then the population converges to a stable stage distribution which is determined by the growth and maturity parameters. The simulation code tracks numbers and biomass is each stage in each simulated year, and calculates catch-at-stage vectors and total yield for each fishery or survey. Output statistics include the mean, variance, minimum, and maximum of population numbers over the simulation period, after allowing an initial period for burn-in. These statistics are also calculated for the recruitment, biomass, spawning biomass, and fishery yield time series.

Equations for the model are as follows:

For years t (1:nyr) and size stage a (1:nclass)

N[t,1] = R[t] R(t) is generated ~ Normal (Rbar, sigmaR) for all t
N[1,a] = N0 Initial population size, input vector

$N[t+1,a] = N[t,a]*G0_a*S_a + N[t,(a-1)]*G1_{(a-1)}*S_a \quad a = 2,3,\ldots,(nclass-1)$
$N[t+1,nclass] = \text{Sum } (a = 1,2,\ldots,(nclass-1)) \text{ of } (N[t,a] * S_a * mat_a)$
where $S_a = \exp(-Za)$ and $Za = NatM + FishM$

Octopus Population Simulations
The model explored for the octopus assessment is defined as having 6 stages: 5 immature stages and one stage for reproductive adults (Figure 22.A2.1). The five immature stages are selected to represent the range of octopus sizes seen in fishery and research data, and to roughly correspond to the presumed maximum lifespan of *E. dofleini*. The first size stage consists of newly settled octopus weighing < 3kg, the remaining stages are 6 kg intervals. The growth parameters are set so that the immature stages may either grow one size step with Pr(g1) or stay in the same size class with Pr(g0). Stages 2-5 also have a fixed probability of maturing (transitioning to stage 6) in each time interval. Natural mortality is presumed to decrease with increasing size for immature octopus as the number of predators decreases. The natural mortality of the final stage is set very high so that there is virtually 100% mortality. The fishery is modeled to represent the Pacific cod pot fishery, with maximum selectivity on the largest animals. There is also a simulation of the AFSC Bottom Trawl survey, which selects for small octopus but catches some larger octopus, and Pacific cod predation, which selects exclusively for small-medium octopus.

The model and some typical outputs are shown graphically below. This simulation model was run for a variety of input parameters and fishing scenarios; the results of these simulations were presented to the Plan Teams at their September 2016 meetings and will eventually be presented in a scientific publication. The population model will also be used to generate a range of simulated data sets with different levels of variance in the population parameters; these simulated data sets can then be submitted to a quantitative catch-at-age model to see how accurately it estimates the true population parameters. The Teams are encouraged to suggest additional scenarios for simulation.

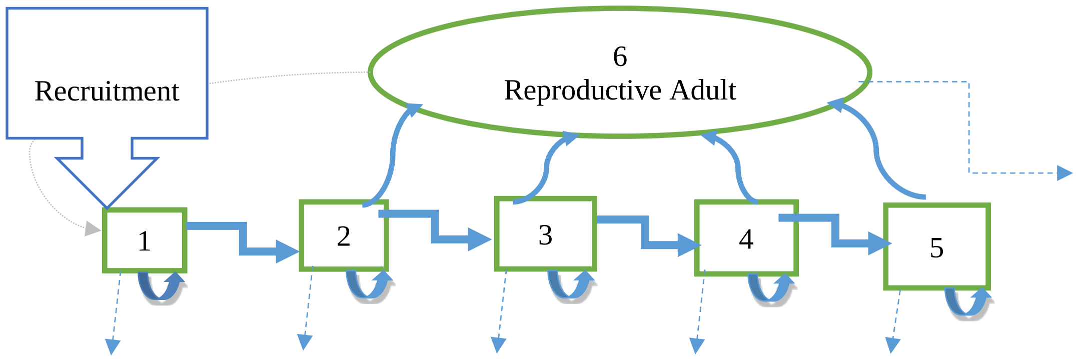
Simulation Models run as of 9/1/16:

Model 0 – fully deterministic (all input parameters constant), constant recruitment, no fishing
Sensitivity analysis

Model 1 – fully deterministic model, constant recruitment, fishing effects
Model 0 with FPot ranging from 0.01 to 0.6 – Yield, population effects
Cordue model – age based (g)=0 with same parameters from CIE review

Model 2 – deterministic growth, maturity, and mortality; random recruitment, fishing effects
Recruitment variance vs. Biomass and Yield variance
Model 2 with added directed fishery on sizes 2-3
Model 2 simulating catch-at-age data for fitting with SS3

Fig 22.A2.1 Size-Stage Octopus Population Model and Base Parameter Values



Population Structure and Growth Variables

	1	2	3	4	5	Adult
Size (kg)	< 3	3 < 9	9 < 15	15 < 21	21 +	
Mean Wt (kg)	0.5	6	12	18	24	22
Mnat	0.7	0.5	0.2	0.1	0.1	10
Pr(Mature)	0	0.1	0.5	0.75	1.0	
Pr(grow 0)	0	0	0	0	0	
Pr(grow 1)	1.0	0.9	0.5	0.25	0	
InitSize%	0.55	0.15	0.10	0.08	0.02	0.1
N0	5,500	1,500	1,000	800	200	1,000
Fsel – Pots	0	0.1	0.5	1.0	1.0	1.0
Fsel– BTsur	1.0	0.1	0.1	0.1	0.1	0.1
Fsel- Cod	1.0	0.5	0	0	0	0

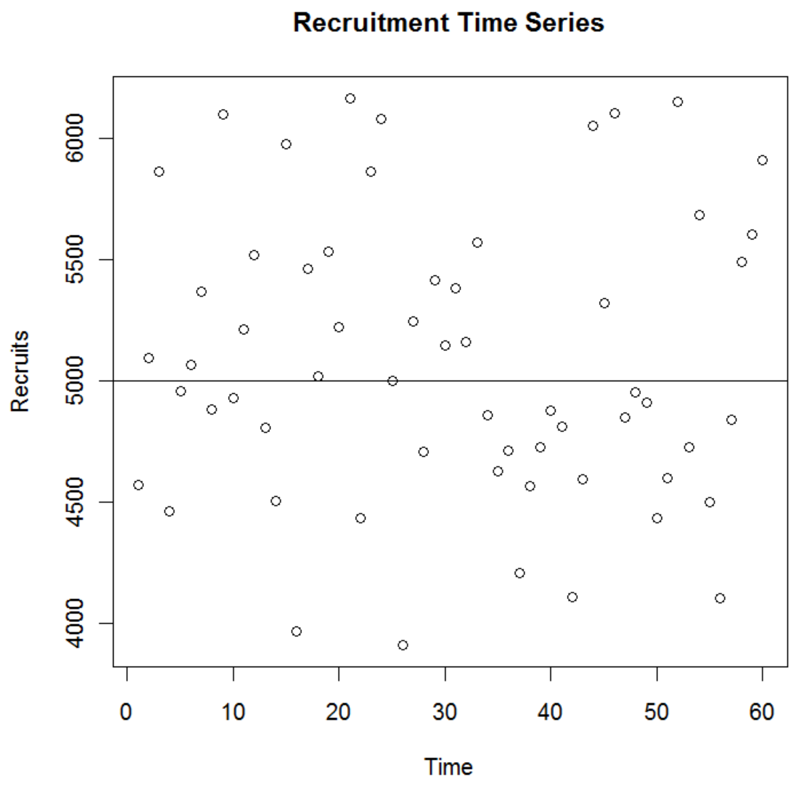
Run Variables

Nclass	6
Yrs, burn	60,10
N0_all	10,000
Rbar	5,000
sigmaR	0
Ftot - Pots	0
Ftot- BTsurv	0
Ftot- Cod	0

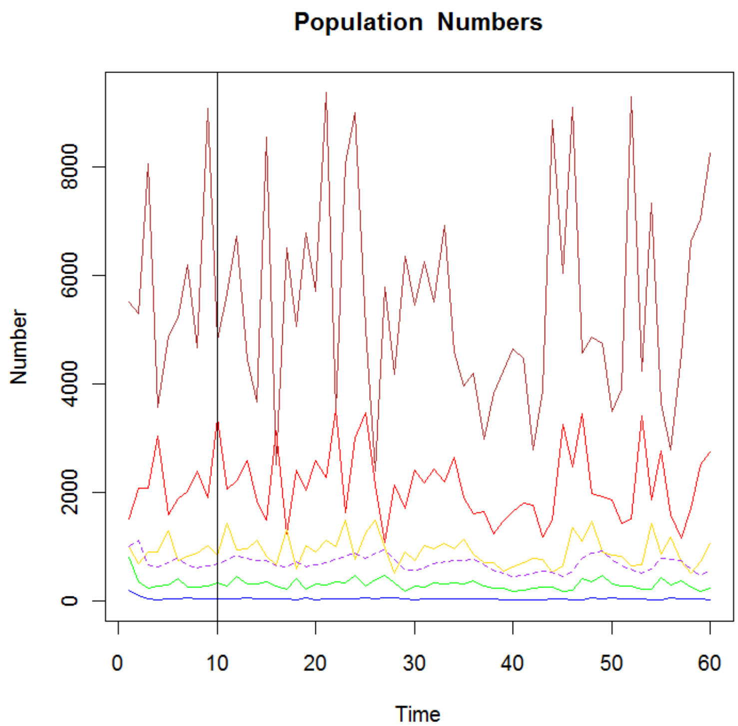
Calculated Variables / Outputs (units)

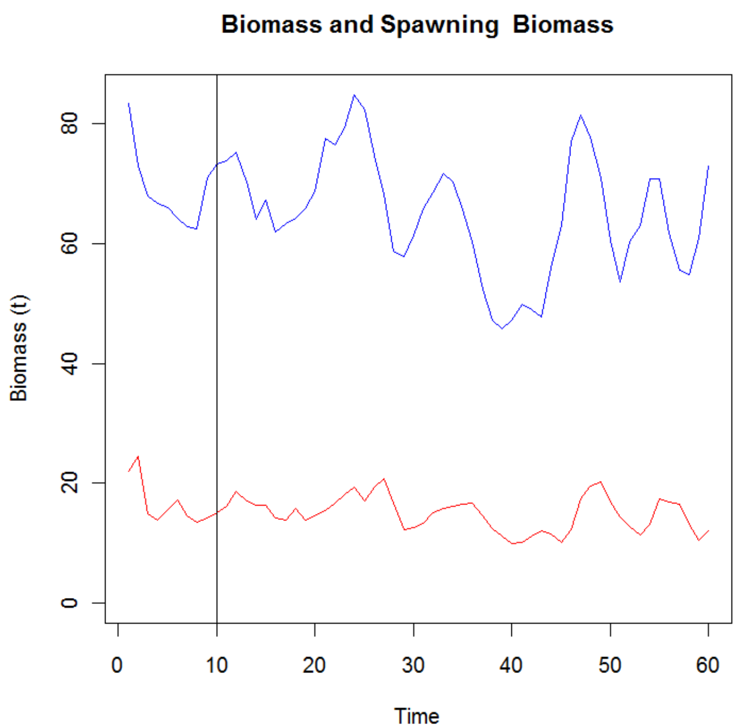
N(t,i) vector	Numbers at stage i	#	Matrix
N(t+1,i)	Numbers next year	#	
SF(t,i)	Size Frequency	%	Matrix
R(t)	Recruitment	#	Vector
B(t,i), B(t)	Biomass	t	Vector
SpB(t,i), SpB(t)	Spawning Biomass	t	Vector
CAAF(t,i)	Catch by stage	#/stage	Matrix
Yield (t)	Fishery Yield	t	Vector

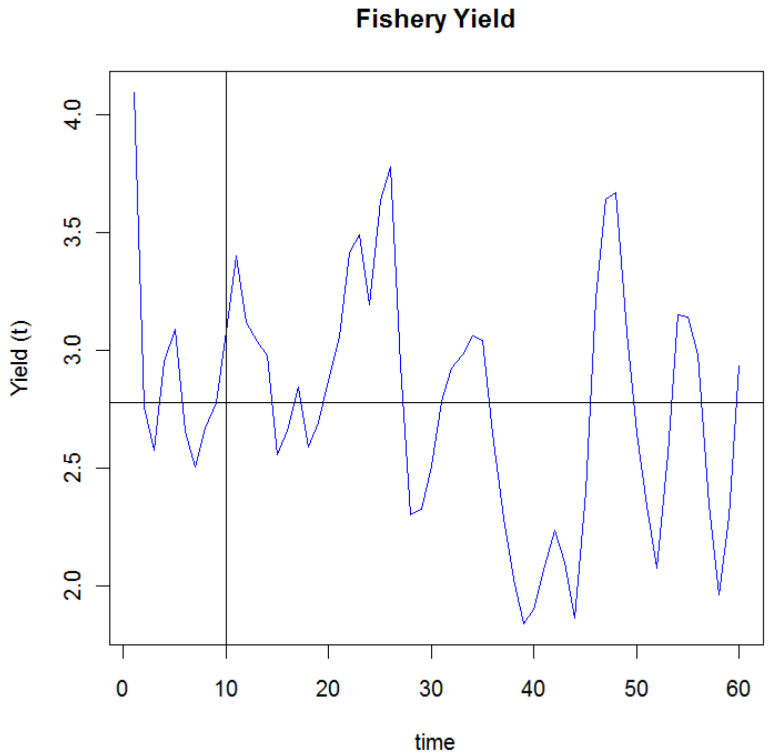
Fig 22.A2.2 Examples of Population Simulation – Model 2



Colors for population numbers plot: Stage1 brown, Stage2 red, Stage3 yellow, Stage4 green, Stage 5 blue, and Stages 6 dashed violet







R screen output:
Initial Biomass and Population Size = 83.4 10000
Final Biomass and Population Size = 64.19 12850
Average Fishery Yield = 2.77
Ending Size Frequency = 0.642 0.212 0.082 0.017 0.001 0.042

Mean, Stdev, Min, and Max of time series (after burn-in) for Nt[i] plus Rt, Bt, SBt, Yield

	Mean	StDev	Min	Max
N1	5439.621	1928.922	2396.300	9362.232
N2	2111.981	655.904	1080.014	3517.209
N3	926.392	273.844	508.435	1494.725
N4	297.731	82.156	173.443	475.272
N5	36.803	10.030	21.300	58.368
N6	678.445	129.686	452.450	946.847
Rt	5439.621	1928.922	2396.300	9362.232
Bt	64.956	10.011	45.855	84.812
SBt	14.926	2.853	9.954	20.831
Yield	2.752	0.515	1.840	3.776