Atlantic States Marine Fisheries Commission

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MEMORANDUM

TO: American Lobster Management Board

FROM: American Lobster Technical Committee

DATE: July 15, 2016

SUBJECT: Evaluation of Management Tools to Increase Egg Production in SNE

At the May 2016 meeting, the Board requested the American Lobster Technical Committee (TC) conduct analysis on management strategies that may achieve a 20%-60% increase in egg production in the Southern New England (SNE) lobster stock. The TC investigated how trap reductions and changes to the gauge size may impact egg production. **Analysis on gauge size changes suggests that, both inshore and offshore, minimum gauge size changes result in larger increases in egg production than maximum gauge size changes over the same increment across all scenarios.** Analysis on trap reductions was problematic and there were multiple concerns regarding the underlying assumptions relating traps to exploitation rates. **While the results suggest that the current 25% reduction in traps may result in egg production increases up to 13.1%, other research suggests that the increase may be much less than this and concerns regarding this analysis prevent the TC from supporting the use of trap reductions as a means to increase egg production.** In particular, the analysis is predicated on the assumption that fishermen maintain a constant soak time when their trap allocation is reduced, an assumption that can be difficult to test and is not supported by empirical data. As a result, the TC cautions the Board in pursuing further trap reductions as a means to reduce exploitation or increase egg production.

Most importantly, the TC highlights that increases in egg production will benefit the stock only if environmental conditions are favorable for larval development and settlement. As mentioned in the April 2016 TC memo to the Lobster Board, recruitment appears to be decoupled from SSB (Figure 1). This could potentially be the result of reduced mating success, environmentally-mediated changes in survivorship, and/or increased predation (Figure 1). Prospective increases in egg production will only benefit the stock if recruitment rates remain constant or improve. As a result, this management strategy may not result in stock improvements if current environmental conditions persist. **The TC warns the Board that increasing egg production by 20% to 60% is unlikely to be sufficient to prevent further declines in the SNE lobster stock.** Projection analyses provided by the TC indicate that an 85% reduction in exploitation would be necessary to stabilize the stock

This report is split into three sections. The first section defines the various metrics the Board has used to describe population components in SNE. This is included to address questions raised by Board members at the May meeting regarding the difference between egg production and spawning stock biomass. The second section describes expected increases in egg production from changes to the gauge size. The third section reviews analysis on trap reductions, concerns with the relationship between traps fished and exploitation, and potential increases in egg production which may result if soak time remains constant.

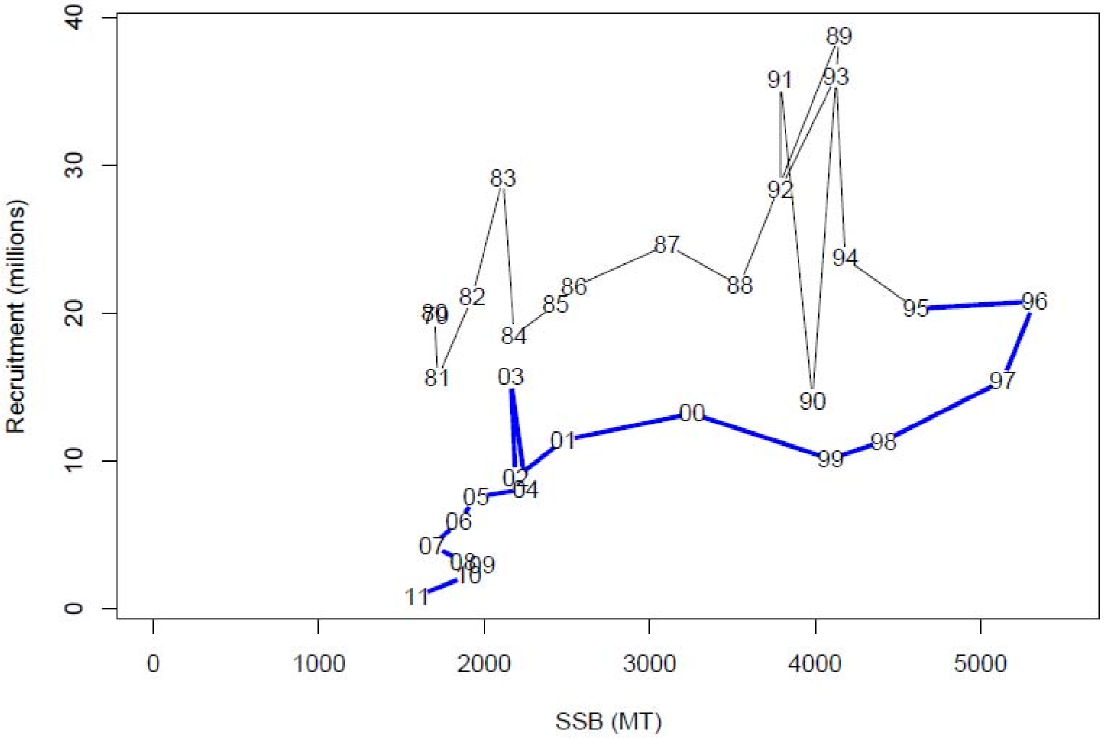


Figure 1. The relationship between model-based spawning stock biomass and recruits from 1979 to 2011. The blue line denotes the trajectory from 1995 – 2011 (recruiting to the model from 1998 to 2014).

1. Metrics To Describe Population Components

Over the past year, the TC has used several metrics to describe population conditions in the SNE stock and present simulation model results attempting to predict outcomes of various strategies. These metrics have included population size, reference abundance, spawning stock biomass (for just females, and for both sexes combined), and egg production. These terms are not interchangeable, and here we attempt to clarify the various metrics and terms used, how they are related, and propose clearer terminology moving forward.

<u>Reproductive population:</u> This is a newly proposed term to describe the number of mature females AND males within the population. Given uncertainties regarding male maturity and the

size at which they become reproductively active, the maturity ogive for females is applied to the males. As written, “reproductive population” would be the number of mature individuals within the population. Biomass estimates could also be applied, using the appropriate length-weight relationships, to generate a “reproductive biomass” estimate. These are the terms the TC will use moving forward, whenever analyses incorporate mature individuals of both sexes.

Population size: The number of individual lobsters (both sexes) in the population. The model used by the stock assessment currently includes all lobsters 53 mm carapace length (CL) and larger in the estimates of population size.

Reference abundance: The number of individual lobsters (both sexes) that are 78 mm CL and above present in the population at the beginning of the year (January 1), plus those lobsters that will molt into this size range during the year. This size range applies to both stocks (GOM and SNE). This is intended to represent the component of the population that is or will be available to the fishery within the year.

Spawning stock biomass (“SSB”): The total weight of sexually mature females in the population. On recent occasion, estimates of SSB presented to the Board have included both mature females and males, and this was clearly described in accompanying text. However, this may cause confusion as SSB typically refers specifically to females, and in the future will only be used when talking specifically about mature females. The calculation of SSB is based on applying the maturity ogives to the number of females in each length bin to generate the number of mature females at a given size. The length-weight relationship is then applied to the number of mature females within a size bin to calculate the weight of mature females in each size bin. The weights for each size bin are then summed to produce a total estimate of the weight of mature females present in the population, resulting in spawning stock biomass.

Egg production: The estimated number of eggs produced by the mature females in the population were calculated based on the maturity ogive, the probability at-length of carrying a clutch in a given year, and the fecundity-at-length, applied to the number of female lobsters in individual size bins. We used the same maturity ogive as the 2015 Stock Assessment. Probability at-length of carrying a clutch in a given year was based on the molt probability at-size curve that was calculated for the growth matrix, based on tagging data, for the 2015 Stock Assessment. On an annual basis, approximately half of the mature females < 120 mm CL should be carrying eggs (because of the trade-off between molting and spawning, females in this size range produce a clutch every other year). Thus, the estimate of total egg production is appropriately divided in half to represent this 2 year cycle of actual egg production. Note that there is some uncertainty as to how many females actually follow this 2 year cycle, as opposed to either annual egg production, or lengthier intervals between clutches.

Fecundity-at-length is based on the fecundity-at-length relationship published by Estrella and Cadrin (1995). Individual fecundity can be highly variable, and dependent not only on female size, but also potentially on female condition (health) and the quantity and/or quality of sperm received by the male. See details on egg production calculation in section 2.

In the past, the Board and the TC have moved away from using egg production to describe population conditions due in part to large mismatches in egg production at the recruit level (egg-per-recruit) and observed stock conditions (see Addendum VIII). Accurate estimates of egg production require assumptions regarding population stability that have proved troublesome in the past, and there is no new information to improve these estimates.

The TC would like to note that it is important to consider management measures that would protect mature individuals of both sexes. While males can and do mate with multiple females in a reproductive season, there is a large degree of uncertainty regarding their capacity to accomplish multiple matings, and how density and molt timing might impact this. Given the depleted condition of the SNE stock and uncertainties regarding reproduction, both males and females should be conserved in order to provide the best potential for egg production.

2. Potential Egg Production from Gauge Size Changes

The objective of this work was to quantify prospective American lobster (*Homarus americanus*) egg production increases for the Southern New England (SNE) stock if minimum and/or maximum carapace length regulations were to change. Gauge changes in theory would result in more fecund females remaining in the population longer and higher egg production than under the current regulations. Increasing egg production in SNE will enhance the potential for improved recruitment if environmental conditions become favorable.

Methods

The influence of gauge changes on egg production was estimated with a projection model. The projection model uses the University of Maine (UMaine) population model outputs, such as population abundance and size structure, for the SNE stock. The terminal year of the UMaine output and stock assessment (2013) is used to represent the current population structure. For further description of the UMaine model, please see the Atlantic States Marine Fisheries Commission Lobster Benchmark Stock Assessment Report (ASMFC, 2015).

The projection model carries forward the terminal year results of the UMaine model, allowing for investigation into how changes in lobster life history, fishing pressure, and/or population dynamics would influence the population structure in future years. Only females were included in this analysis as the desired units were egg production and management measures often affect females differently than males. Selectivity of lobsters to the fishing industry (via minimum and maximum gauge changes) was the only input that varied in this analysis, with all other adjustable parameters held constant. Starting abundances at length and growth matrices were as described in the 2015 Assessment (ASMFC 2015). Fishing mortalities were estimated based on mean rates from 2008 to 2012, and described on a quarterly basis. Harvest rates from quarter one through four were 0.07, 0.42, 0.43, and 0.30, respectively. Future recruitment was also held constant, and was calculated as the average female recruit abundance from 2012 to 2014. Natural mortality was set as 0.285 for all size classes and held constant over time.

Egg production was calculated using probability of molting information and a length-based fecundity model. Probability of molting at a given size was used to infer what proportion of females at size would not have a clutch at a given time, assuming that in a given year a female lobster is either molting or carrying a clutch. Molting probabilities were the same as used in the 2015 Stock Assessment and derived from historic tag-recapture data from the SNE region only. Probability of molting (P_M) was described as a logistic function (Figure 2a) using carapace length (CL, mm):

$$P_M = \frac{1}{1 + e^{-4.186+0.0439*CL}}$$

However, it's assumed that all lobsters are molting at a minimum of once every 4 years (P_M=0.25). Thus, all probabilities less than 0.25 were set to this minimum (Figure 2a). Probability of carrying a clutch (P_C) was then calculated as the difference between one and the probability of molting (Figure 2b):

$$P_C = 1 - P_M$$

Fecundity at size (F_L) was modeled as a power function using carapace length (Figure 2c), derived from Estrella and Cadrin (1995):

$$F_L = (0.000497CL^{3.7580})1.01522$$

Egg production for the inshore and offshore contingents were calculated as:

$$EP_L = P_{C,L}\ x\ F_L\ x\ N_L$$

where EP_L is egg production at length, $P_{C,L}$ is the proportion of female lobsters carrying a clutch at the given size, F_L is the fecundity at length, and N_L is the number of females at size at the end of the second quarter (June). Given the abundances at size are in 5 mm bins, egg production estimates were averaged across the 5mm bin.

Egg production estimates from model projections are based on comparing different projection scenarios once the population has reached an equilibrium state, in this case after about 10 years (2025). We present results for equilibrium states because:

- The initial size compositions for projection runs are based on the size composition from the terminal year of the assessment model, which are notoriously unstable.
- Because lobsters grow slowly, it takes several years for changes in gauge size to take effect, particularly for larger lobsters.
- We wished to analyze separate scenarios for inshore and offshore SNE which have different legal sizes and fishing pressures, and length compositions for subsets of the stock are unknown.

Hereafter, egg production estimates are presented for the projection model results in year 2025, representing when the population has presumably reached equilibrium. These results should not be interpreted as needing 10 years for management measures to have an effect, though some management measures would require time for the benefits to be fully realized. The current min/max regulations inshore and offshore were also used to calculate baseline egg production for assessing increases in production relative to the status quo.

Both inshore and offshore analyses were tested by changing minimum and maximum gauges by 1mm units. The 1mm increment was chosen in an effort to provide changes relevant to industry units (just over a 1/32" gauge change) while also using units relevant and discernable in the projection model. Relative egg production increase was calculated by dividing the egg production of the population under new gauge changes by that under the current gauge sizes and subtracting by one. Values near zero indicate little or no change in egg production, while values greater than zero reflect relative egg production increases from the current conditions.

Results

Figures 3 and 4 represent resulting egg production increases inshore and offshore when adjusting the minimum or maximum gauge only and keeping the other gauge at the current size. At equilibrium and with the minimum gauge held constant at the current sizes, a max gauge size approaching 4 inches would be necessary to achieve a 20% or greater increase in egg production both inshore and offshore (Table 1). Holding the maximum gauge size constant, a minimum gauge size of 92mm (3 5/8") inshore and 95mm (3 ¾") offshore would result in a 20% increase in egg production. A 60% increase in egg production is obtainable when only changing the minimum gauge inshore or offshore, but is unobtainable when only adjusting the maximum gauge (Table 1).

Evaluating resulting egg production increases under the different combinations of gauge changes (Figures 5 and 6) also indicates that a given incremental change in gauge size is more effective for the minimum gauge than the maximum. Maximum gauge changes have minimal effect on egg production unless significant maximum size reductions are implemented. Combinations of gauge changes that result in 20% and 60% increases in egg production from Figures 5 and 6 are presented in Table 1. The wide range of maximum gauge changes with an associated minimum gauge change (Table 2) highlights the impact of the minimum gauge relative to maximum gauges both inshore and offshore.

Efforts were also made to estimate potential egg production increases resulting from standard gauge sizes across SNE. There were several challenges to this analysis; namely that baseline egg production levels inshore and offshore differ due to the disparate gauge sizes and the geographic spread of females inshore versus offshore is unknown. As a result, only a range of potential egg production increases could be estimated. Two scenarios were considered: 89mm-140 mm (3.5”-5.5”) and 89mm-127mm (3.5”-5”). Under the first scenario, increases in egg production could range from 0.01% to 9%, depending on where the females primarily reside. In the second scenario, egg production could increase from 0.19% to 9%.

Limitations and Future Consideration

While these egg production estimates attempt to account for several important biological aspects of American lobster, there are a few assumptions and sources of uncertainty worth mentioning:

- Natural mortality is held constant for all size classes, where in reality natural mortality likely decreases with age and size. While there is currently no information regarding natural mortality specifically at larger sizes, the assumption of constant M may result in underestimating egg production, particularly for scenarios with maximum gauge changes.
- Current egg production conditions were based on regulations for inshore and offshore; however, current regulations vary by Lobster Management Area (LMA). Thus, egg production potential may vary within inshore and offshore regions from these estimates depending on the LMA of interest.

Additionally, projections should be interpreted in light of the model assumptions and aspects of lobster life history, data used for the UMaine model, and UMaine model output. Considerations include:

- Uncertainty associated with the model functions are not incorporated in the projections (i.e. mean model fits are used). Results are based on one set of functional forms used to describe lobster population dynamics.
- Uncertainty associated with the lack of data on the growth, reproduction, and natural mortality for the offshore lobster population.

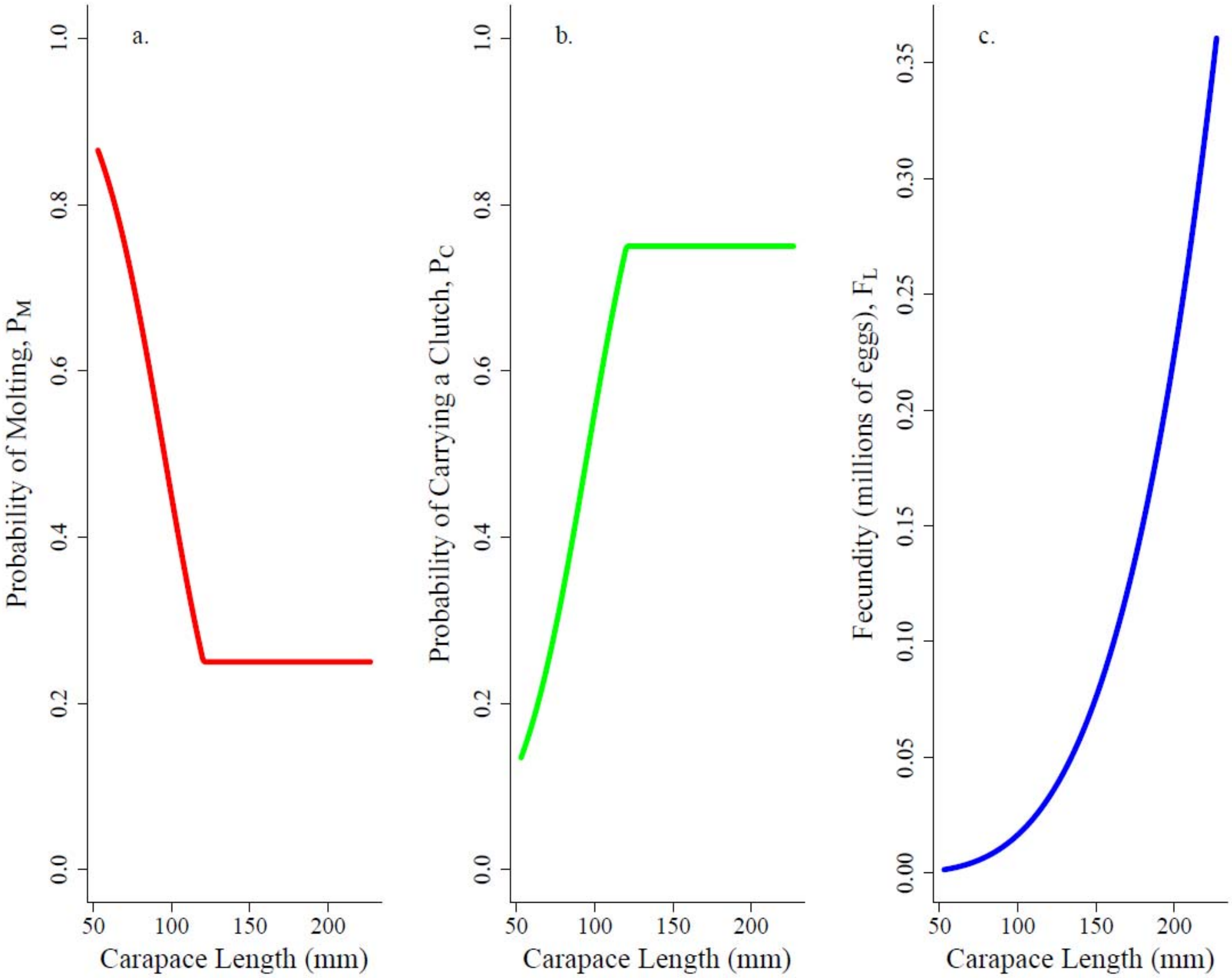
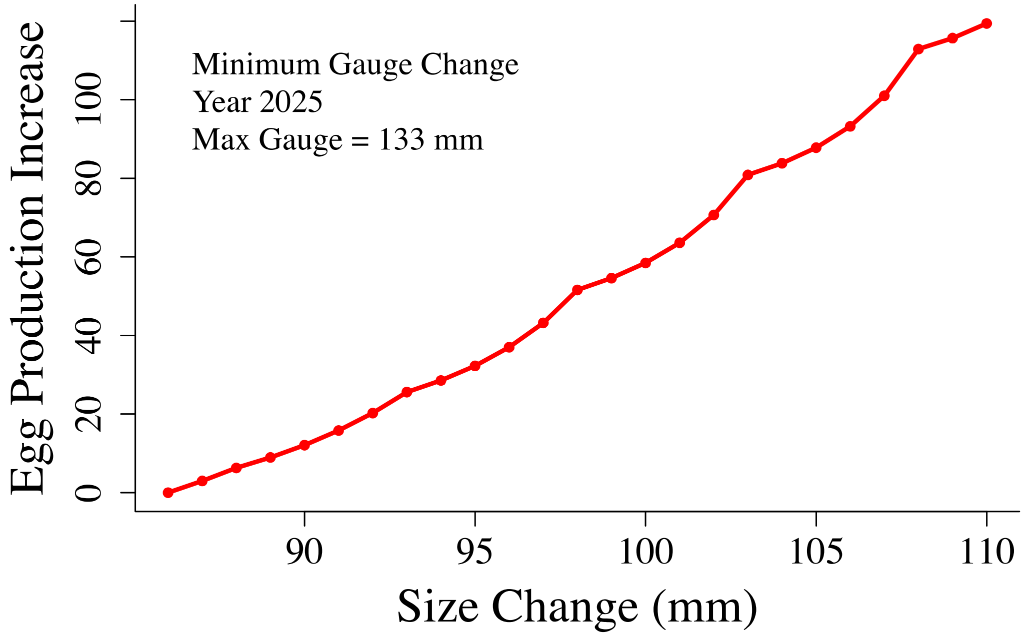


Figure 2. Probability of a female molting in a given year (a), probability of a female carrying a clutch in a given year (b), and fecundity (c) at given carapace lengths (mm). Multiple or ranges in sizes for a given maximum gauge indicate that all of the referenced sizes, accompanied by the corresponding minimum gauge size listed, result in the specified percent increase in egg production.



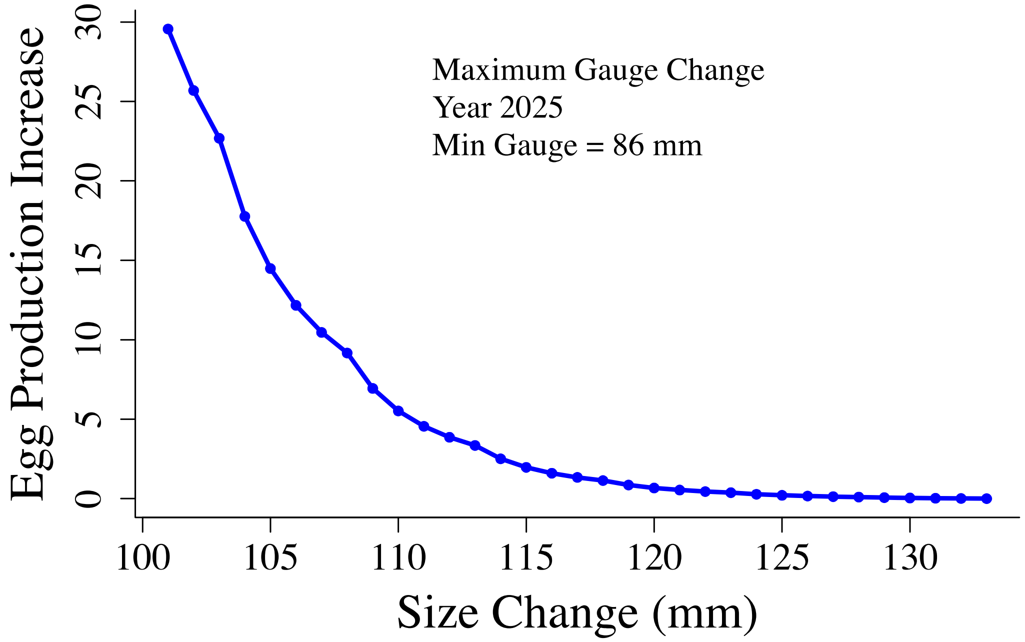


Figure 3. Inshore egg production percent increases from minimum (top, red) and maximum (bottom, blue) gauge changes. The current inshore gauge size is 86-133mm or 3 3/8”-5 ¼”.

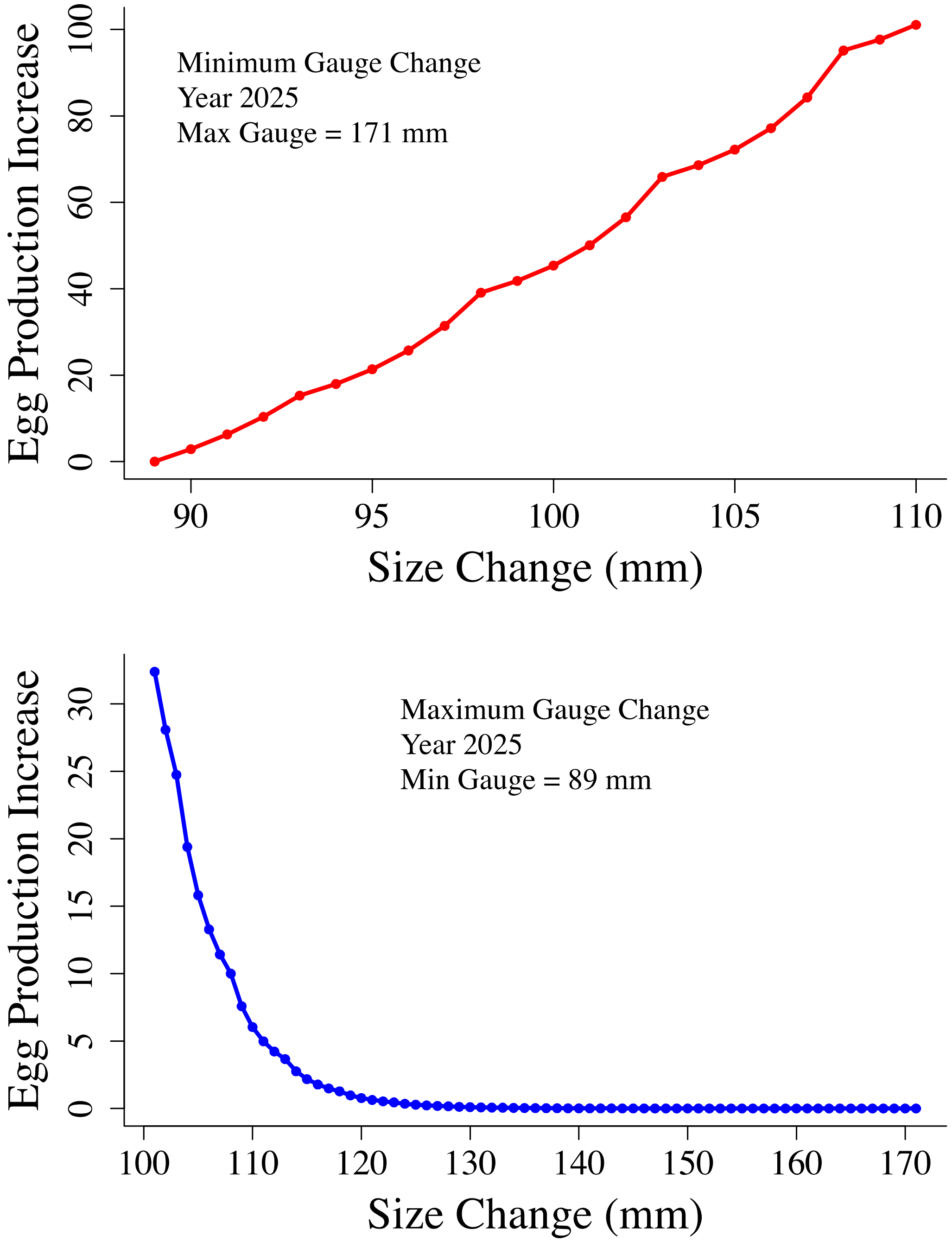


Figure 4. Offshore egg production percent increases from minimum (top, red) and maximum (bottom, blue) gauge changes. The current offshore gauge size is 89-171mm or 3 17/32”-6 ¾”.

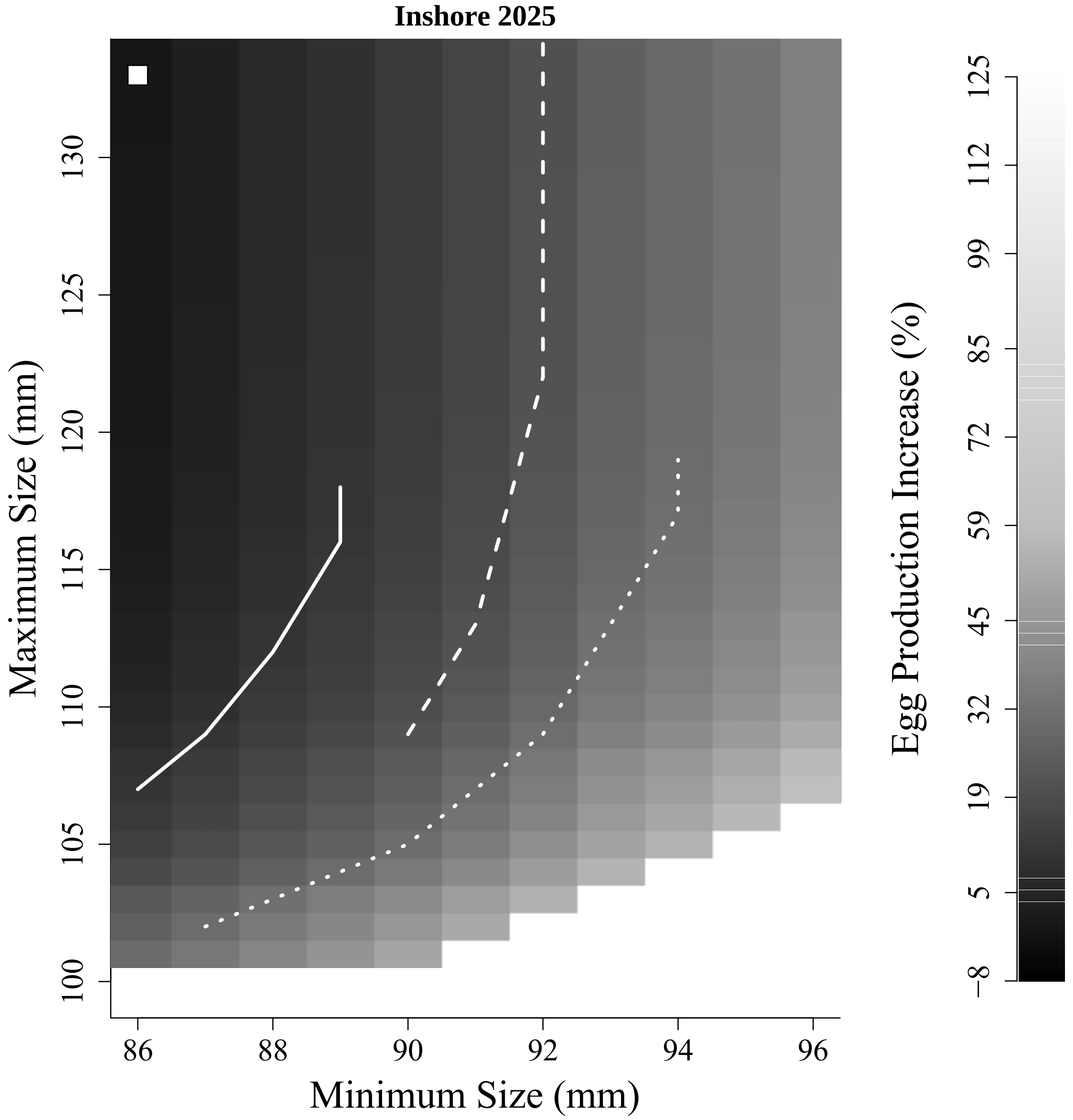


Figure 5. Inshore minimum/maximum gauge change scenarios and corresponding egg production changes from the current gauges (white boxes). Egg production is expressed as percent increases from the current conditions. Egg production increase contours for 10% (solid line), 20% (dashed line), and 30% (dotted line) are drawn for reference. Gauge change scenarios that would result a legal size range of 10mm or smaller (bottom right) are not presented, with space representing absent results and no increases in egg production. The current inshore gauge size is 86-133mm or 3 3/8”-5 ¼”.

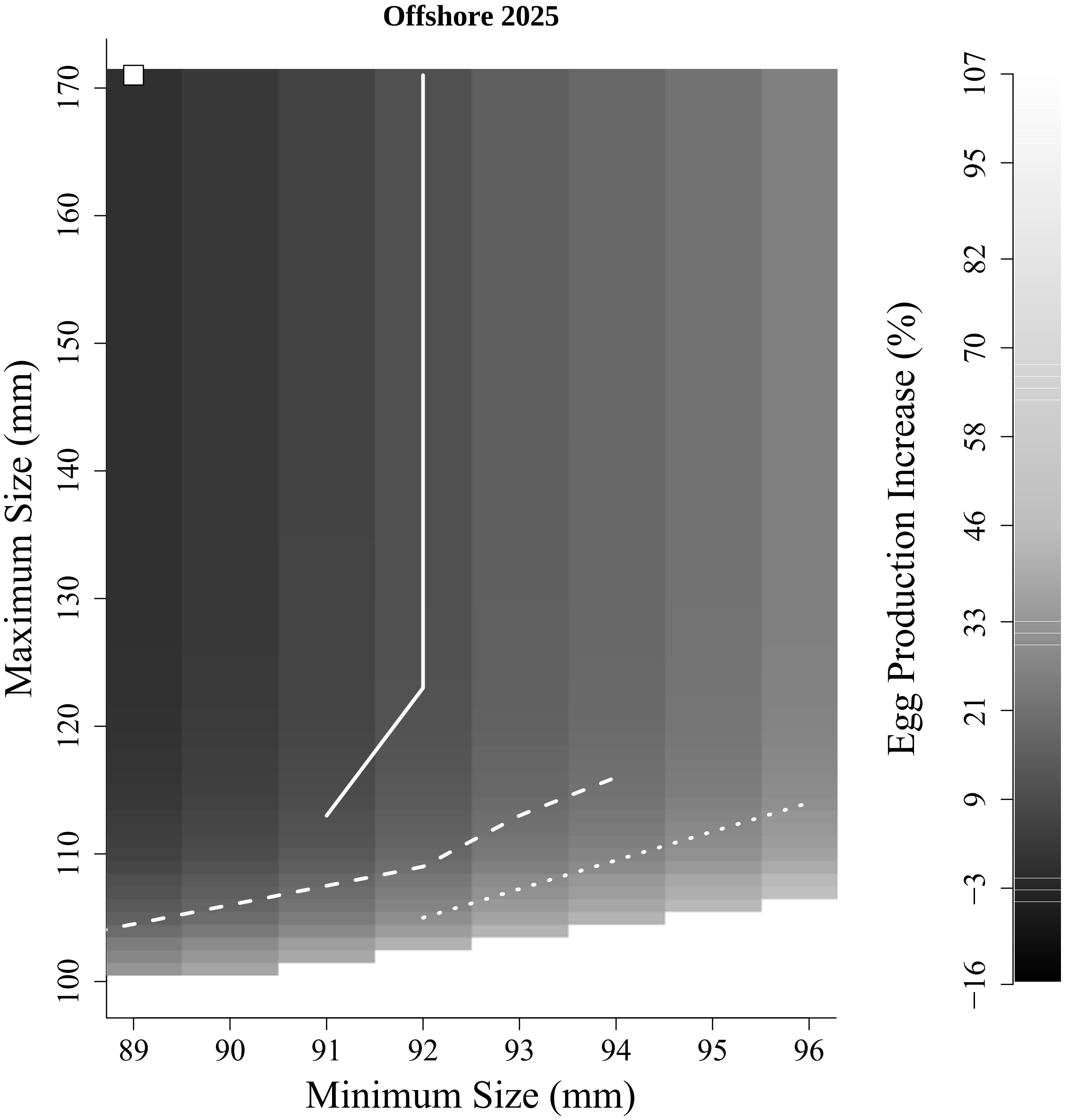


Figure 6. Offshore minimum/maximum gauge change scenarios and corresponding egg production changes from the current gauges (white boxes). Egg production is expressed as percent increases from the current conditions. Egg production increase contours for 10% (solid line), 20% (dashed line), and 30% (dotted line) are drawn for reference. Gauge change scenarios that would result a legal size range of 10mm or smaller (bottom right) are not presented, with space representing absent results and no increases in egg production. The current offshore gauge size is 89-171mm or 3 17/32”-6 ¾”.

Table 1. Gauge changes (in mm) for inshore/offshore under equilibrium projections that result in at least 20% and 60% increases in egg production when the other gauge is held at its current size (extracted from Figures 3 and 4). NA indicates that the target percent increase is not obtainable with one gauge constant and the other varied over the range assessed in this analysis. The current inshore gauge size is 86-133mm and the current offshore gauge size is 89-171mm.

Scenario	20%	60%
Inshore Minimum Change	92	101
Inshore Maximum Change	103	NA
Offshore Minimum Change	95	103
Offshore Maximum Change	103	NA

Table 2. Gauge changes (in mm) for inshore/offshore under equilibrium projections that result in a 20% and 60% increases in egg production. The current inshore gauge size is 86-133mm and the current offshore gauge size is 89-171mm.

	20% Egg Production Increase		60% Egg Production Increase	
Scenario	Minimum	Maximum	Minimum	Maximum
Inshore	90	109	96	107
	91	113	97	109
	92	122-171	99	115
			100	120, 121
Offshore	88	103	100	111
	92	109	102	119
	93	113		
	94	116, 117		

3. Potential Egg Production from Trap Reductions

The Lobster Technical Committee was tasked with providing advice on how the currently-planned trap reductions would affect the SNE lobster stock, particularly in regards to egg production.

The relationship between fishing effort and fishing mortality rate is extremely problematic, particularly for trap fisheries because multiple factors beside the number of registered traps affect catch and mortality rates, including latent effort, how often the traps are fished, trap soak times, the spatial distribution of the resource, and changing fleet characteristics.

Despite these caveats, we attempted to model the relationship between the number of actively fishing traps (AFT) and fishing mortality using data and exploitation estimates from the SNE stock assessment. We then estimated new exploitation rates, assuming a 25% reduction in traps from the terminal year and projected how these would change egg production relative to current exploitation.

All previous trap reduction programs utilized in the SNE lobster stock were aimed at reducing the total trap allocation for each fisherman (which included both active and latent pots). The analyses presented here use the number of actively fished traps as documented in the 2015 Stock Assessment in order to relate effort to resulting exploitation. This analysis makes the following assumptions;

1. **The 25% trap reduction will actually result in a 25% decrease in actively fished traps.**
2. **Other aspects tied to fishing effort (i.e. soak times, duration of fishing season, etc.) do not change as fishers compensate for the decrease in fished traps.**

A time series of AFT in the SNE stock area and corresponding exploitation rate (model-estimated SNE exploitation) from 1981-2013 were obtained from data presented in the latest (2015) Stock Assessment. The plot of fishing exploitation vs. total traps reveals two apparent regimes in this relationship (Figure 7). Exploitation is stable and high as effort increased from 1981 to 1998; however, as the fishery decreased and minimum legal sizes increased, the exploitation rates dropped to lower levels. Based on this, we examined two relationships between exploitation and numbers of traps; one using the entire time series (hereafter “all years”) and a second using only the years since 1999 (hereafter “recent years”).

Models fitted through these points using maximum likelihood estimation and assuming a Michaelis-Menten response function are very stable, presumably because the function is forced through the origin and there is little variation in exploitation at high trap values. To better examine the uncertainty in this relationship, we bootstrapped 1,000 models, with replacement, for both “all” and “recent” years and recorded the model-predicted exploitation rates at the current trap levels and after the 25% trap reduction (Figures 8 and 9 respectively). Based on the data for all years, a 25% reduction in traps may reduce exploitation rates from 0.270 to 0.239 constituting an 11.6% reduction (95% CI: 6.5% -16.3%). Similarly, for data from recent years, the planned trap reduction may be expected to reduce exploitation rates from 0.207 to 0.176 or a 14.3% reduction (95% CI: 3.5% - 21.2%).

Population simulations were then run with the range of bootstrapped exploitation rates for both all years and recent years, and pre- and post-reduction, to get equilibrium female and male length compositions for pre- and post-reduction scenarios. We calculated egg production using the same egg production model detailed in Section 2 and compared egg production estimates for pre-reduction to post-reduction exploitation rates.

The population simulations under different exploitation rates suggest only small increases in the abundance of lobsters above legal size (Figure 10). With annual egg production rates applied to the female lobsters, egg production is projected to increase by 9.6% (95% CI: 4.5 – 13.0%) when exploitation curves are based on all years' data and 13.1 % (95% CI: 2.6 – 19.7%) when based on recent years' exploitation data (Figure 11). A critical assumption to these estimates is that soak time does not change as trap allocations are reduced. If fishermen do reduce their soak times (haul their remaining traps more frequently) to compensate for a reduction in traps, the expected increase in egg production would be reduced.

TC Concerns with Trap Reduction Analysis

Although these analyses accurately depict the observed relationship between active traps fished and exploitation in SNE, they are based on the explicit assumption that soak time is constant. This assumption is not valid. Empirical data presented in the 2015 ASMFC lobster stock assessment for MA and CT demonstrate substantial variability in soak time, particularly in recent years (Figure 12). The only true measure of effort in trap fisheries is the number of trap hauls (preferably standardized to soak time, Miller 1990). The total amount of effort exerted by an individual trap is directly proportional to how often it is hauled and the trap's efficiency at the point at which it was hauled (Miller 1990). Both of these factors are directly influenced by soak time. The shorter the average annual soak time the more often that trap is hauled during a year. Conversely, the longer the average annual soak time, the less often that trap is hauled during a year.

In addition to the frequency with which traps are hauled, a lobster trap's efficiency (number of lobsters it retains/number of lobster it encounters) typically reaches its maxima between 1 to 4 days in inshore areas (Thomas 1973, Fogarty & Borden 1980, Auster 1986, Estrella & McKiernan 1989) and 5 to 9 days in offshore areas (Skud 1979). Trap efficiency is further complicated by interactions with population density, trap saturation, interspecific competition, bait type and quantity, trap size, spacing (trap density), trap design, and water temperature (Miller 1990).

Furthermore, soak time is directly affected by fishing behavior which is influenced by fishing costs (bait and fuel), catch rates of lobsters, and the market price of lobsters (Miller 1990). Trap density experiments conducted off of Monhegan Island in the GOM demonstrated that a 67% reduction in active traps fished resulted in only a 16% reduction in catch when soak time was held constant (Wilson 2010). Additionally, soak time experiments conducted as part of this study suggest that at a 5 day soak time, lobster traps within the study area were operating 80% below their maximum efficiency (Wilson 2010). A trap reduction program in the Florida Keys spiny lobster fishery also had limited success in reducing fishing mortality. Specially, management measures which removed roughly 40% of the traps in the fishery (939,000 traps in 1991 to 568,000 traps in 1995) only reduced fishing mortality by 16% (Mueller et al., 1997). Both studies demonstrate an ability to maintain or increase catch rates in trap fisheries by hauling substantially less gear more often on shorter and substantially more efficient soaks. As a result, quantifying a standard unit of effort in trap fisheries is extremely complex and notoriously elusive. Additional information on the relationship between traps fished and exploitation can be found in Appendix 1 - November 2010 ASMFC Lobster Technical Committee Memo to the Lobster Board.

The relationship between traps fished and exploitation presented in this analysis may depict an unrealistically optimistic view of potential reductions in exploitation associated with lower numbers of traps fished. The traps currently fished in the SNE lobster fishery are nowhere near their saturation point and current average soak times in the SNE lobster fishery are well below maximum efficiency. This is supported by the observed substantial increases in CPUE in SNE that are concomitant with the observed declines in the number of active traps fished (Figure 13 a & b). This suggests that the bootstrapped estimates of the relationship between traps fished and exploitation with extremely steep slopes (those whose point of inflection falls to the left of the bootstrapped mean; Figures 8 and9) and long stable asymptotes are likely to be more realistic.

Conclusions

If the assumptions of this analysis are upheld (a critical and unlikely caveat) the best case scenario the TC would expect is a 14.3% reduction in exploitation with a corresponding 13.1% increase in egg production. When compared to the simulation analyses previously presented to the board, the TC would expect the SNE lobster population to continue to decline from its current levels. Additionally, the Lobster Technical Committee is very concerned that this analysis is simply a mathematical exercise that overlooks the many intervening factors described above. The TC is not able to predict fishermen behavior that would affect how often traps are hauled or how many allocated traps are actually deployed. However, it is highly likely that fishermen will respond to trap reductions by trying to maintain fishing effort by hauling the traps they do have more frequently, or in some areas (LMA2) by purchasing additional (mostly latent) trap allocation. This behavioral compensation would offset the intended effects of trap reductions in relation to exploitation rates. As such, **the TC strongly cautions the Board against using these analyses to quantify or predict current or future reductions in exploitation related to trap reductions.**

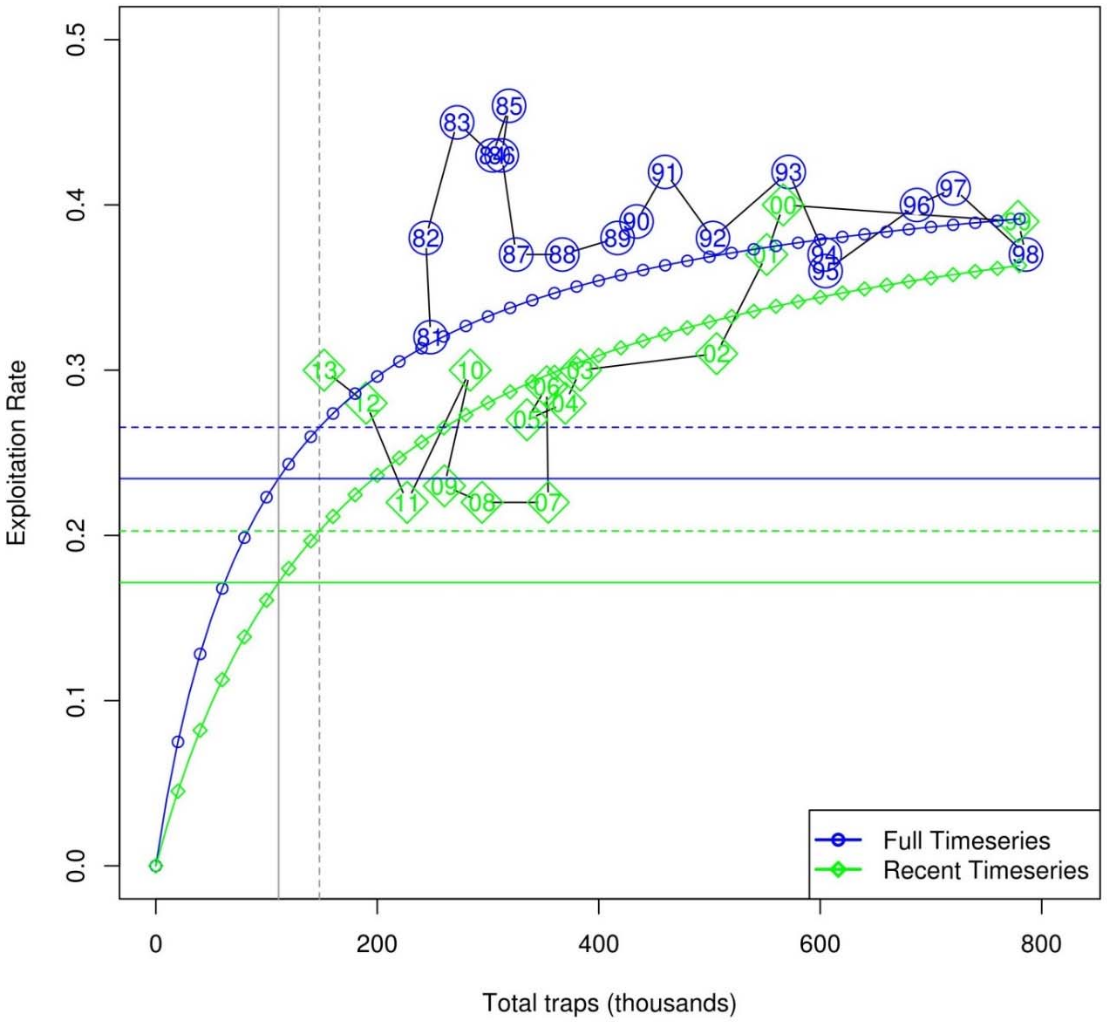


Figure 7**.** Plotted time series of total traps in the SNE fishery and exploitation rates from the assessment model. Numbers indicate the last two digits of the year. Early year's data and the fitted model for all years are plotted in blue with recent years data and model plotted in green. The vertical solid and dashed gray lines represent the post- and pre-trap reduction levels respectively. Horizontal lines represent estimated pre- and post-reduction exploitation rates (dashed and solid respectively) for all and recent years models (blue and green lines respectively).

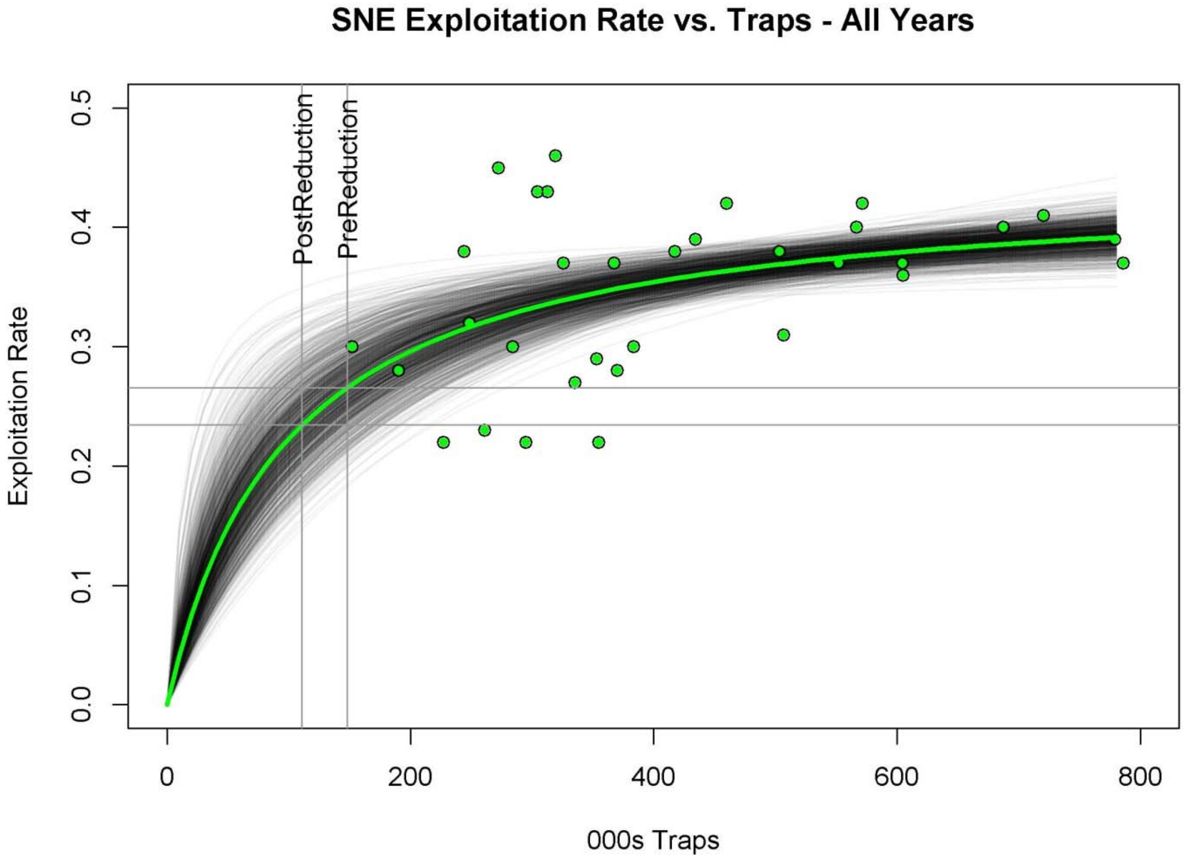


Figure 8**.** Relationship between effort and exploitation for all years with the model curve for the full data set (green line) and each of the 1,000 bootstrap models (gray lines).

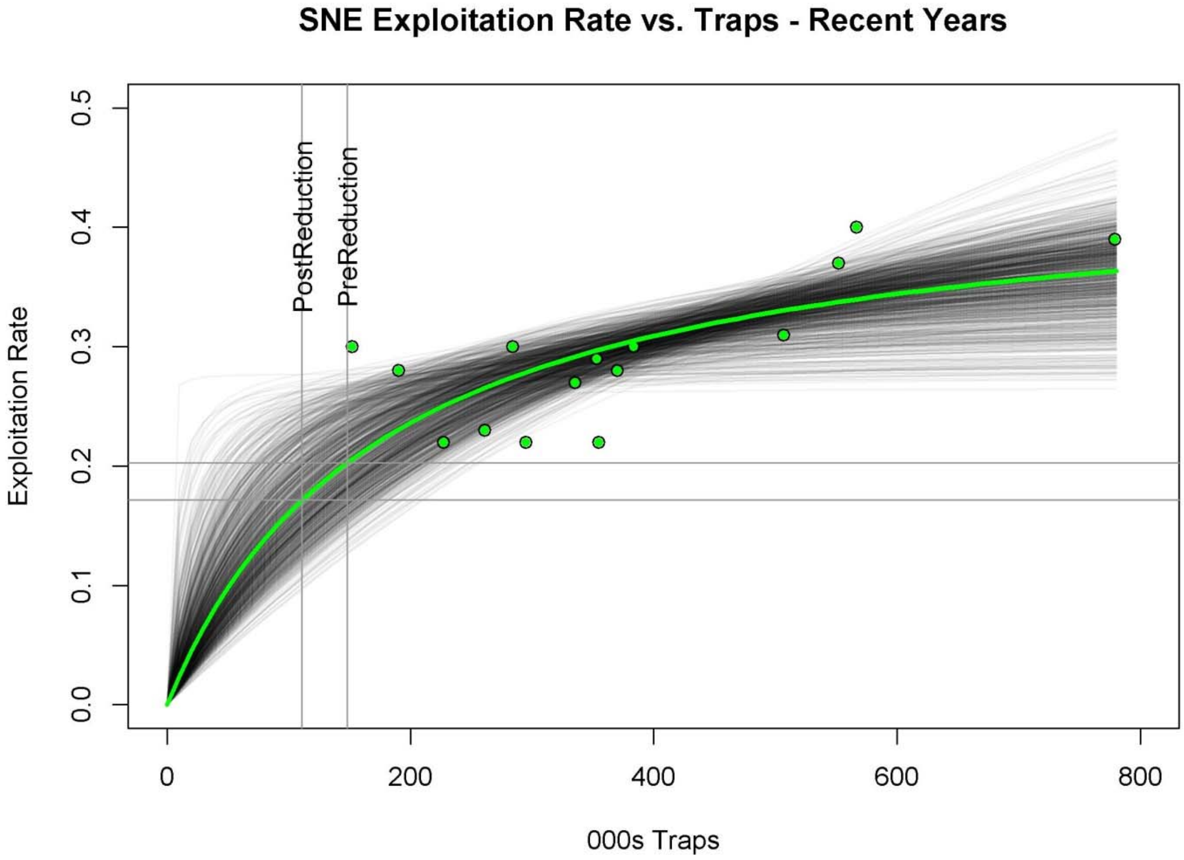


Figure 9. Relationship between effort and exploitation for recent years with the model curve for the recent data set (green line) and each of the 1,000 bootstrap models (gray lines).

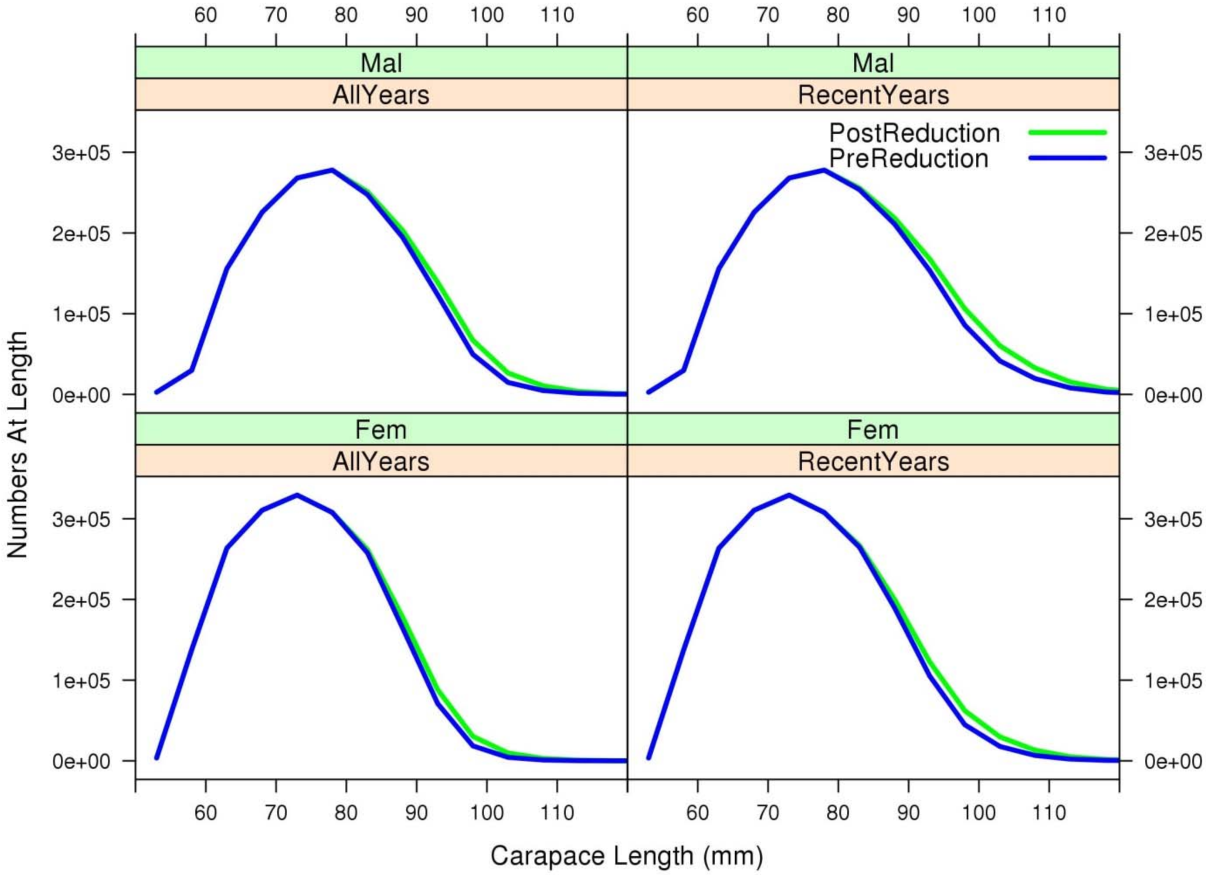


Figure 10. Mean numbers of lobsters at size for males (top) and females (bottom) from population simulations based on exploitation curves from all years (left) and recent years (right). Separate length compositions are shown for the pre-trap reduction (blue) and post-trap reduction (green) scenarios. Models assume basecase assessment model growth and natural mortality rates and continued current recruitment levels.

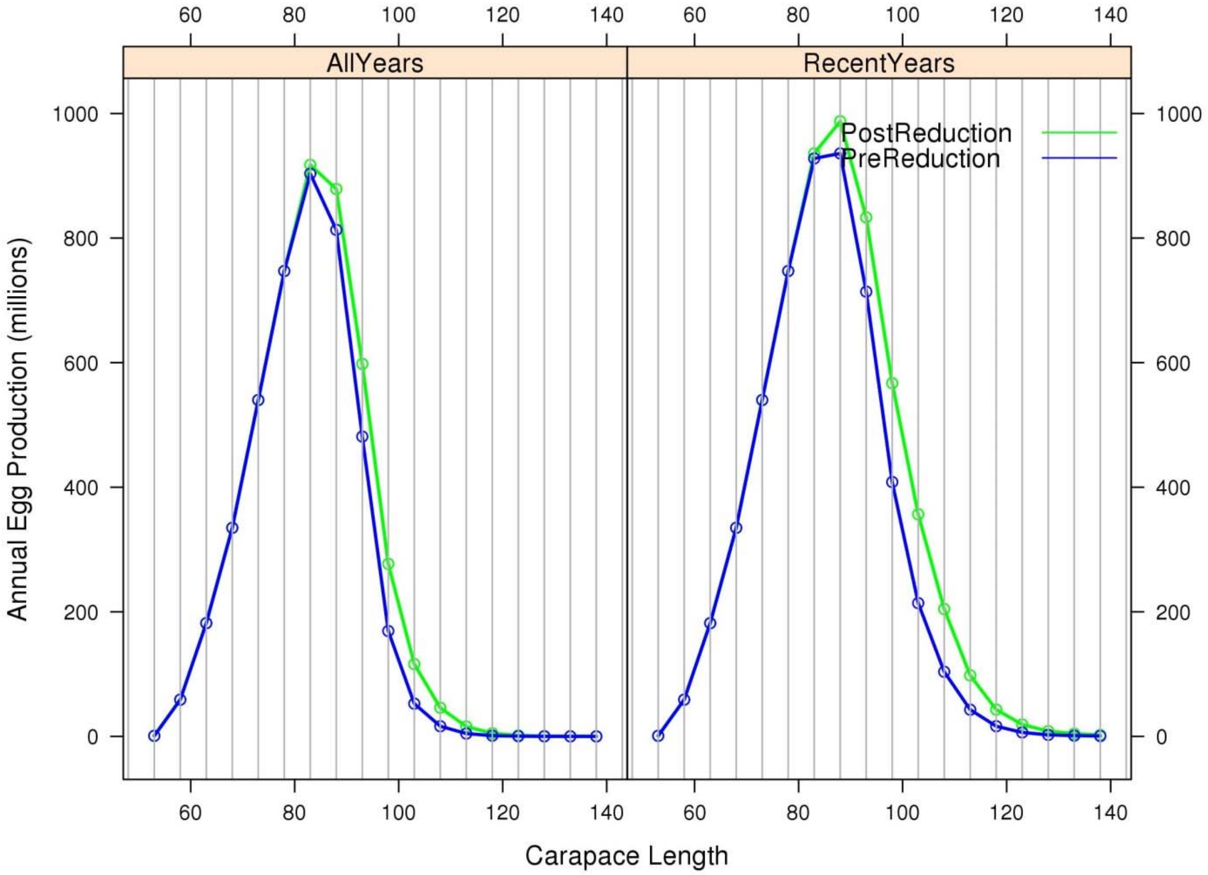


Figure 11. Egg production at-size based on the female numbers-at-size from Figure 4.

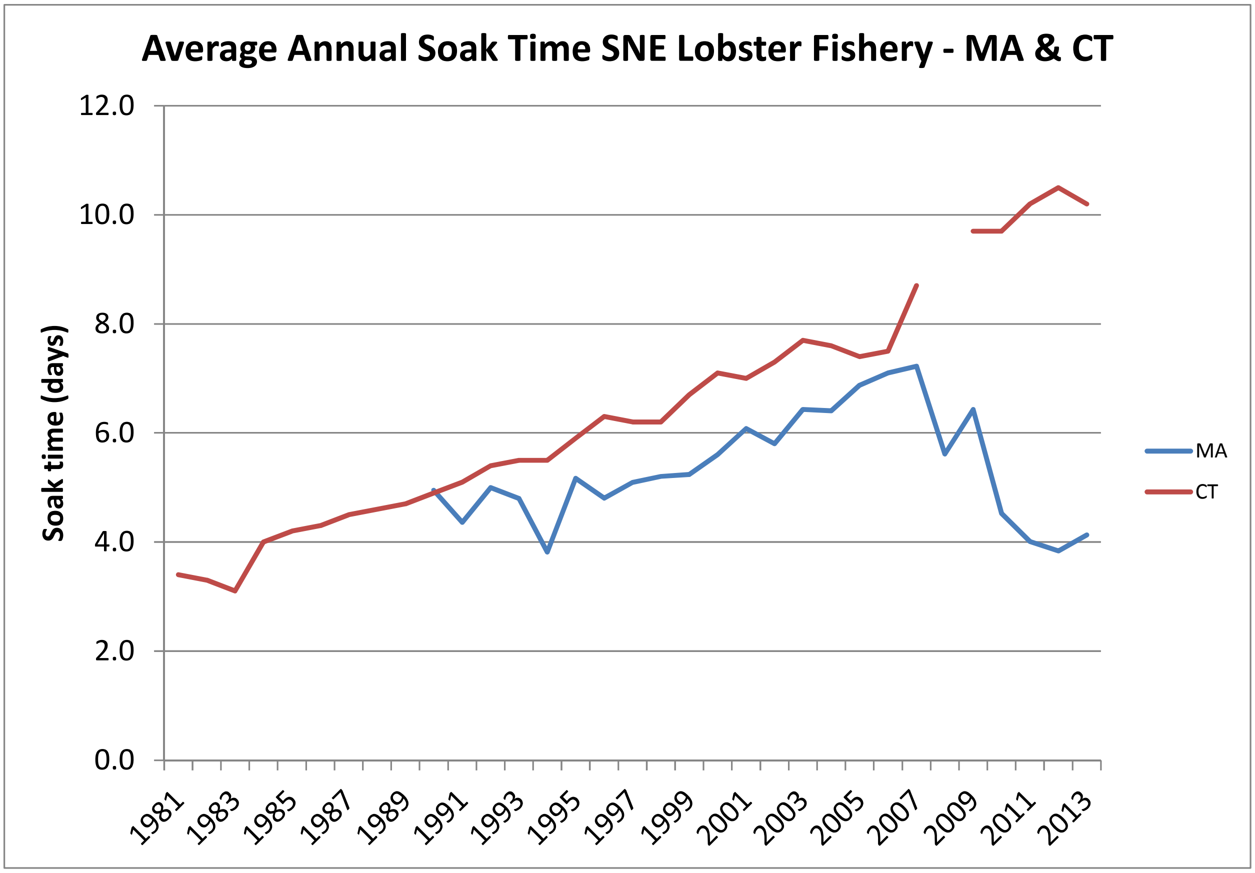
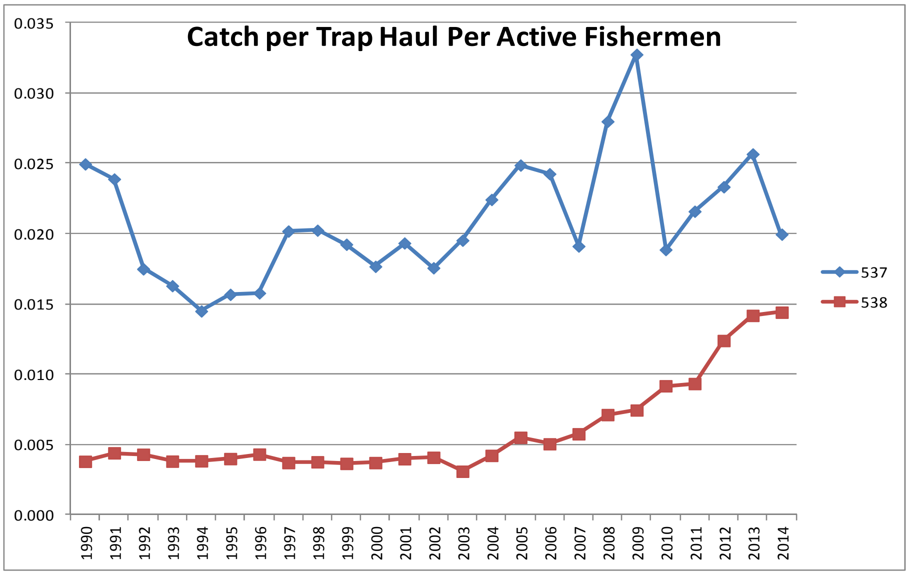
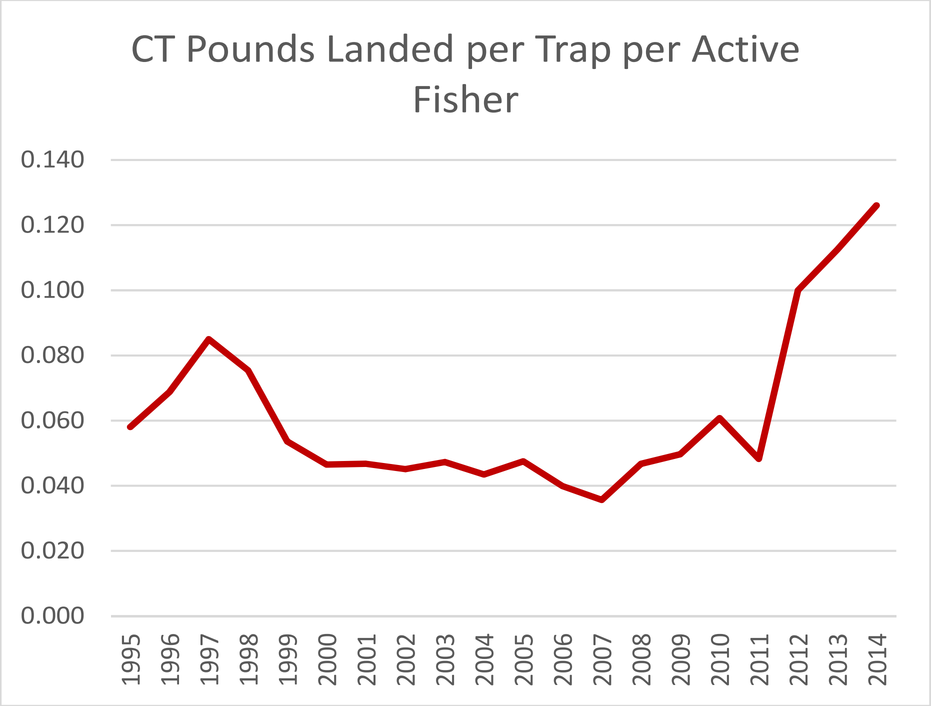


Figure 12. Annual mean soak time for SNE lobster fishery in CT (red) and MA (blue) from harvester reports 1981 to 2015.





Figures 13a and 13b. CPUE – Catch per trap haul per active fishermen in SNE – MA (a) and CT (b)

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