Evaluation of Expert Report by D.H. Bennett, "Effect of Sport-Fishing Regulations on Striped Bass Population and Predation in the Delta"

by

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I am Louis W. Botsford, a professor in the Department of Wildlife, Fish and Conservation Biology at the University of California, Davis. My curriculum vitae is attached as Exhibit A. I am an expert in the area of fish population dynamics and population estimation. I have provided advice on fish population dynamics and fisheries to governments at the state, federal and international levels. For example, I am currently on the Scientific and Statistical Committee of the Pacific Fishery Management Council, one of the regional federal fishery management bodies. I served on the Science Advisory Team for the implementation of the Marine Life Protection Act, a California law mandating implementation of Marine Protected Areas along the California coast. I also recently served in an Expert Workshop on Marine Protected Areas and Fisheries Management for the Food and Agriculture Organization of the United Nations (see publication 129 on CV). I served on a committee concerned with the decline of striped bass for the California Water Resources Control Board in the early 1980s, and I had a contract with California Department of Fish and Game for modeling striped bass shortly thereafter.

I have been asked to evaluate an expert report entitled, "The effect of sport-fishing regulations on the striped bass population in the Sacramento-San Joaquin Delta" by Dr. David H. Bennett (referred to hereinafter as the Bennett report). In particular I will address the claims that: (1) the analysis by D.H. Bennett is based on "accepted fisheries population models" (Bennett report, p. 8), (2) "By eliminating both the 18-inch minimum size and 2-fish bag limit regulations, the population of striped bass would decrease by approximately 60-70%" (Bennett report, p. 8),), and (3) "All of these sources lead to the conclusion that eliminating the sport-fishing regulations (minimum size limits, creel limits) will probably reduce the Delta striped bass population by approximately 60-70%" (Bennett report, p. 26).

I. My General Conclusions

A. The report by D.H. Bennett does not follow the accepted method for estimating the decline in a population due to a change in regulations. Rather the report is a number of separate calculations, none of which produce a justifiable, reliable estimate.

B. It is likely that eliminating regulations would reduce the striped bass population, but it is impossible to predict accurately the amount by which it will be reduced because of great uncertainty in: (1) the stock-recruitment relationship for this local population of striped bass, especially at low abundance and (2) the response of fishing effort (anglers) to the change in fishery regulations and to changes in abundance and size structure of the fishery.

C. The report by D.H. Bennett ultimately determines final population equilibrium (a 60-70% decline) by claiming that "At about a 60-70% overall population decrease the resulting CPUE would be similar to the current CPUE, so the striped bass population would reach a lower equilibrium, subject to other environmental factors (see D.5 of the Bennett report). No supporting logic or rationale is given for choosing this as an equilibrium condition, nor is any other logic or rationale given for choosing the value of a 60-70% decline. It is not clear whether the word "population" here means population abundance, population biomass, population recruitment, or some other population indicator. Since CPUE is an index of abundance this equilibrium condition implies the population will have the same abundance after regulations are removed.

II. Accepted Method for Calculating Dependence of Abundance on Regulations

The accepted method for calculating the change in abundance of a fished population is used in virtually all fisheries management where sufficient data are available (Sissenwine and Shepherd 1987, Mace and Sissenwine 1993, Restreppo, et al. 1997, Ralston 2002). It is based upon the mathematical condition for an equilibrium state in a population model that keeps track of age structure and has a density-dependent relationship between total egg production by the population each year and the number of one-year-old recruits (Sissenwine and Shepherd 1987, Botsford 1997). This relationship is commonly called the stock/recruitment relationship.

The stock-recruitment relationship has an important effect on population dynamics because it is density dependent. That is, when a population is small, egg production is low and recruitment will be low. If the population increases a bit, egg production will be higher and recruitment be higher in proportion to egg production (on the left in Fig. 1, at low egg production). However, at higher population levels (toward the right in Fig. 1), when egg production is high an increase in egg production will not cause as large an increase in recruitment. Thus the stock-recruitment relationship in Fig. 1 describes a declining survival from egg to age-1recruitment (i.e., the ratio of recruitment to number of eggs) as the population egg production increase (i.e., moving to the right in Fig. 1). This decrease in the fraction surviving from eggs to recruit is caused by density-dependence, which is essentially a "crowding" effect due to limited space or food. This decline in recruit-to-egg survival as the population becomes larger keeps the population from becoming extremely large, and it eventually goes to an equilibrium level.

The equilibrium level of a population can be determined graphically from a plot of this relationship (Fig. 1) (Sissenwine and Shepherd 1987, Botsford 1997).

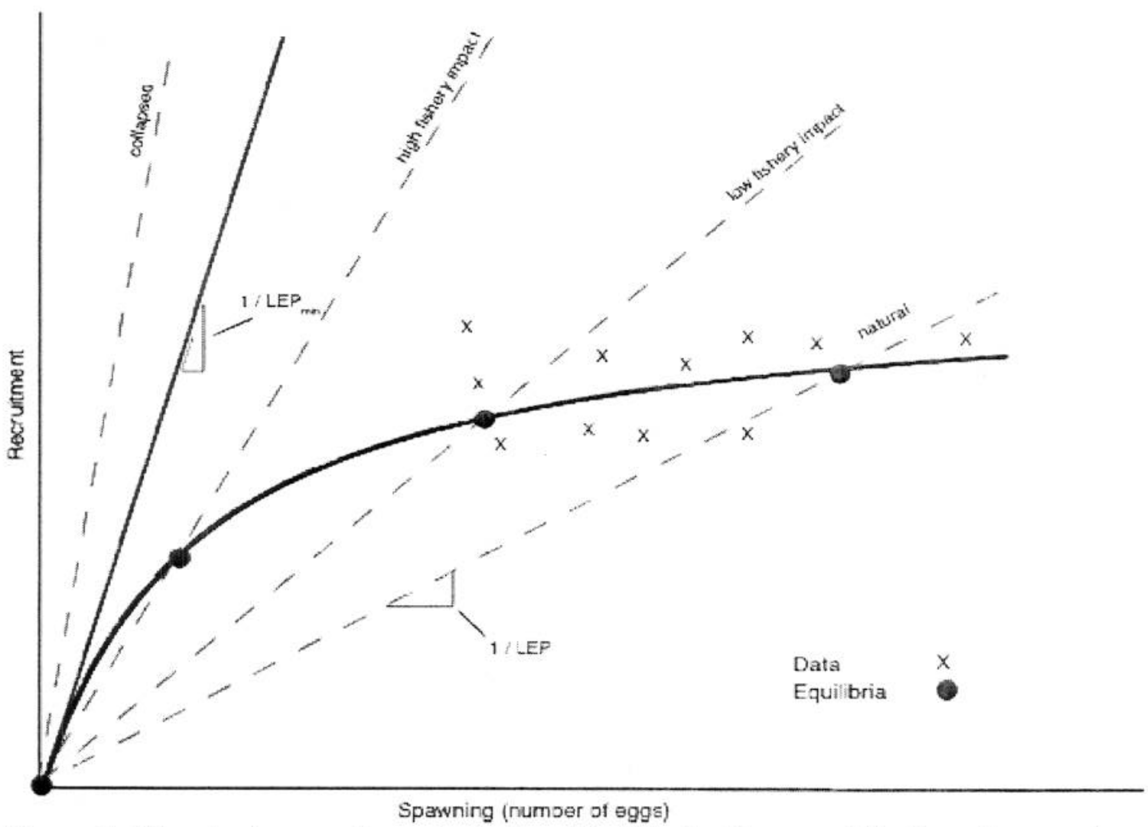

Figure 1. The stock-recruitment relationship (the bold, curved line), and examples of the graphical solution for equilibrium recruitment. The stock-recruitment relationship (curved line) is the number of age-1 recruits that would result from the number of eggs produced by the population in a specific year. The equilibrium can be found by drawing a line through (0,0) with slope 1/LEP, where LEP is lifetime egg production. The equilibrium is where this line crosses the stock-recruitment curve. Note that as the fishery impact increases, fish do not live as long and LEP declines causing the line to be steeper, and the equilibrium to move to the left. When the slope of the line becomes steeper than the slope of the stock-recruitment curve at the origin, the equilibrium is at zero, i.e., the population has collapsed. Thus the condition for sustainability is the LEP be greater than 1/(slope at (0,0)). This

value is typically uncertain because we usually have data only at the high values of spawning and recruitment (as shown by the x's).

The equilibrium level of the population will be at the point where a straight line through the (0, 0) point, with a slope of 1/LEP intersects the stock-recruitment relationship. LEP stands for lifetime egg production, which is calculated as the sum over all ages of the fraction surviving to each age times the number of eggs produced at that age. Lifetime egg production (LEP) is essentially the same as eggs per recruit (EPR), a term commonly used in fisheries. The numerical value of LEP depends on fishing regulations since they affect the fraction that survives to each age. As fishing increases, the lifetime egg production decreases, making the slope of the line steeper and the equilibrium moves to the left as illustrated in Fig. 1. This is an important relationship in fisheries management because to maintain a sustainable fishery one wants to avoid having the equilibrium go to zero. That requires keeping the LEP high enough that the intersection of the lines is not zero.

While this method is known to be correct, finding the solution is often difficult, because we do not know exactly what the stock/recruitment relationship looks like at low values. The reason for that uncertainty is that we often do not have population data (i.e., eggs and recruitment) at those low values. In fishery management we try to avoid having low abundance hence we often do not know population behavior at low abundance. California striped bass have not been at low levels since the 1880s, shortly after they were introduced (Leet, et al. 2001). Some populations have gone to population abundance levels low enough that we can estimate the stock-recruitment relationship at low abundance (e.g., Mace and

Sissenwine 1993, Myers, et al. 1999), however we do not know it for California's striped bass.

LEP can be interpreted as a measure of replacement, a familiar concept in the discussion of the growth human populations. Most of us are familiar with the concept of zero population growth (ZPG), i.e., if each couple has two children in their lives the population will remain constant (which is ZPG), if they have less than two children, the population will decline, and if they have more the population will tend to increase. The idea of replacement is that a population can be sustained only if the average individual in the population reproduces enough in their lifetime to at least replace themselves. This concept is the same in fish populations as it is in human populations, i.e., LEP has to be greater than a certain number for a sustainable population. The difference is that we know the minimum requirement for population persistence is two children in human populations, but we do not know how many eggs are needed in the lifetime of a fish for it to replace itself. Fish produce hundreds of thousands of eggs in their lifetime, and a large fraction of them (more than 99%) do not live to adulthood.

III. Bennett Report Did Not Use Accepted Method

The Bennett report did not take the accepted approach to calculating the effects of fishing on populations, and as a consequence the Bennett report overstates the precision with which he can estimate the abundance that would result from removing the regulations ("would reduce the striped bass population by approximately 60-70 %."). (The Bennett report does not explicitly state the precision of this estimate, which is unusual for a scientific estimate, but it gives the impression that the decline is likely to be between 60 and 70 percent.) There are two major sources of uncertainty in this problem: (1) uncertainty in the knowledge of the stock/recruitment relationship for California striped bass at low values, and (2) uncertainty in the LEP, hence the slope of the straight line in Fig. 1. Lifetime egg production (LEP) depends on the survival to each age, and survival to each age depends on the rate of removal of fish from the population at each age. The amount of fishing that would occur at each age after the fishing regulations were removed is very difficult to predict because the amount of fishing effort under unconstrained conditions is not known. The behavior of anglers often depends on the abundance of fish, and the future abundance is not known.

To take the conventional approach to determining the decline in striped bass with the removal of regulations, Bennett would have had to first have to draw the stock recruitment relationship which would have been impossible since we have no data from that curve for low values of egg production and recruitment. He would also have had to draw a line through the (0, 0) point with slope 1/LEP. That would have required him to calculate LEP, which depends on fishing mortality. Since we do not know what the response of anglers to removal of regulations is going to be, that too would have been impossible. Without knowing what either line looked like, he obviously could not have found their intersection.

IV. Bennett's Approach

The approach taken in the Bennett report was to perform a number of calculations involving a number of separate aspects of the decline in striped bass in the absence of regulations. I review each of these here:

IV.A. *Simulation Modeling.* Prof. Bennett described his approach to simulation modeling of California striped bass in Section D.1 of the Bennett report. It involves using a constant survival from eggs to age-1 recruits ("I used his average number of eggs to produce an age-1 fish", Bennett report, p. 14). As described above, and in Fig. 1, in a population with density-dependent recruitment the survival from eggs to age-1 recruitment increases as the population becomes smaller, and vice versa. That was left out of the model of California striped bass in the Bennett report. When the density-dependence is left out of population models they will eventually either decrease exponentially to zero or increase exponentially without bound . Real populations do not behave in that way, hence models without density dependence, such as the one in the Bennett report, are not used to project long-term abundance. If populations did grow exponentially the world would be covered with bunnies.

The results of the simulations are shown in Exhibits H and I of the Bennett report. From the figure in Exhibit I, the population is obviously declining to zero. In the actual striped bass population the survival from eggs to age-1 would increase as depicted in Fig. 1, in a way that would be determined by the shape of the stock-recruitment relationship in Fig. 1. This could cause the population to reach a new low equilibrium, which is not possible in the model in the Bennett report. Since we do not know the exact shape of that relationship, it is impossible to accurately predict where the population will end up in the absence of regulations. His simulation with no density dependence is not a reliable indicator future abundance without regulations.

IV.B. *Removing Creel/Bag Limit.*

Section D.2 of the Bennett report describes an estimate of how many fish would have been caught by anglers in the striped bass fishery between 1976 and 2008 if there had been no creel limit. The resulting estimates are shown in the right hand column in Exhibit B. It is very unusual to present results of an estimation without an accompanying standard error of the estimate or confidence limits to indicate what the range of error might be. This limits the conclusions that can be drawn from this result. Also, the report states that this is a "peer reviewed statistical procedure", but there is no evidence that this application to striped bass was peer reviewed. A peer review would have insisted there be some evaluation of error.

The estimate is based on a method that fits a statistical model to data describing the fraction of fishermen each year that catches 0, 1, 2, 3 .... fish per day. The number of fish caught per day obviously cannot exceed the creel limit. It then uses that model to predict what those fractions would have been if there had been a higher creel limit or no creel limit. For example, in the paper they refer to by Claramunt, et al. (2009), the authors fit kind of statistical model to data from several years describing the fraction of fishermen that catch 0, 1, 2 and 3 fish per day, where 3 is the maximum bag limit in the fishery they were interested in. They then use that model to predict the number of fish that would have been caught in those same years if the bag limit had been 5 fish, and the same abundance of fish had been present each year.

The application to the California striped bass fishery is quite different. The bag limit is two fish, so fishermen can catch either 0, 1 or 2 fish per day.

Furthermore, the analysis in the Bennett report did not use data on the fraction of anglers catching 0, 1 or 2 fish per day, rather they used the mean and standard deviation of the number of fish caught per day. From these two numbers they attempted to estimate the fraction catching 0, 1, 2, 3, 4, 5, 6, ... fish per day. They then added them all up to obtain the results given in the right hand column of Exhibit B. It is difficult to say how well so much can be predicted from so little information, especially in the absence of any analysis or statements regarding the precision of the estimates.

Another source of error in the analysis of creel data is that the analysis in the Bennett report used the data from the striped bass creel census, but assumed that creel census data collection was conducted with standard creel census methodology (According to email from plaintiff dated ?). The problem is that standard creel census methodology seeks a random, representative sample of all anglers. The purpose of the striped bass creel census in the Sacramento/San Joaquin Bay/Delta is to determine the fraction of striped bass with tags, for a mark/recapture study. Because of that they seek a representative sample of the striped bass caught. The functional difference between these sampling approaches that is important here is that the striped bass creel census will likely under sample the number of fishermen who have caught not fish. In fact the instruction manual for the technicians doing the creel sample (CDF&G 2009) makes the primary purpose clear and actually states "Anglers with fish should have priority over anglers without fish." The immediate effect of undercounting the number of fishermen who caught no striped bass would be to bias the distribution of numbers caught to higher values. That would seem to bias the estimate of the number of additional fish that would be caught without an upper limit in a positive direction. Thus the right hand column of Exhibit B of the Bennett report has an unknown positive bias.

At the end of Section D.2 of the Bennett report, these questionable estimates of catches without the creel limit only over the years 1976 to 2008 are used to calculate a mean exploitation rate of 29%. Because the estimate of catches after the removal of the creel limit has a positive bias, the projected exploitation rate of 29% will also be biased high. This presentation of the 29% estimate is then followed by the statement that this would cause the "reproductive potential" to decrease to less than 20% for the population. No basis is given for this calculation there, but the report may be referring to Exhibit G of the "Spawning Potential Ratio." It is difficult to evaluate what the report is trying to say here. Suffice it to say that if the exploitation rate is not as high as the Bennett report estimates, Exhibit G indicate it could lead to values of SPR that are greater than 20%, the critical value invoked in the Bennett report. Also, whatever "critical value" was developed for the striped bass on the east coast would not necessarily apply to the completely different habitat on the west coast.

To summarize the analysis of creel data to estimate the exploitation rate after the removal of the daily catch limit, first the estimate of how many fish will be caught after the size limit and the creel limit are removed is not a routine application of a common method, but rather is an unusual application of a statistically acceptable approach, but no analysis of potential error is given, which is not acceptable for a scientific estimate. Second, the estimate of number of fish caught after removal of the catch limit has a positive bias because of the specific study design of the striped bass creel census. When the facts that this analysis accounted for only a removal of the creel limit, not the removal of the size limit, and that no population response to these was included, the estimate does not appear to be useful in predicting the future exploitation rate, hence it does not provide the required estimate of LEP.

IV.C. *Yield-Per-Recruit Calculations.* In Section D.3 the Bennett Report employs Yield-Per-Recruit analysis. This type of analysis computes the effects of size limits and changes in fishing on the relative numbers at each size and age in a population. It does not account for their effects on the number of recruits in the population, rather all calculations are "per-recruit" regardless of what the annual recruitment of 1 year-olds is. In other words these calculations describe what is happening in a typical cohort, not how many are recruited to begin each cohort. Thus, by themselves, these calculations cannot project the future population equilibrium.

IV.C.1 In section D.3.a and Exhibit C the Bennett report makes the point that if you start with a recruitment of 1,000 fish at age 1, and do not begin fishing until the fish in a cohort are larger than 460 mm (18 in), then the exploitation rate will have no effect on the number that reaches that size. If, on the other hand, you remove the size limit and begin fishing all fish, you will have fewer fish in the cohort reaching 460 mm the harder you fish. These results make sense and seem correct.

However the subsequent statements in this section of the Bennett report, regarding total population abundance, are difficult to follow because the calculations are not given, only the results are stated, and these do not seem to be correct. For example, to convert numbers in a cohort that begins with a recruitment of 1,000 fish the Bennett report apparently multiplies by the total abundance, not the recruitment, to obtain the numbers 50,000 and 119,000. That would not be correct. The report then invokes the exploitation rate of 29% obtained from the flawed creel census to conclude that the sustainable number of harvestable fish would "theoretically decrease 98% to 20,000 with no limits." No formula or other basis for this calculation is given. Without such information, it is impossible to evaluate this analysis in the Bennett report. However, in any event, to calculate the change in population abundance one would need to follow the accepted method presented in Section II, above.

IV.C.2. Section D.3.b and Exhibit D of the Bennett report describe the effect of removing the size limit on the yield that would result from a cohort that began with recruitment of 1,000 fish. As the rate of fishing increases, yield continues to increase if there is a size limit, but if there is not a size limit, the yield begins to decrease, basically because yield is given in terms of total weight, and there are far fewer big fish. These are the expected results from this kind of analysis. However, it is difficult to tell where the California striped bass would be on the x-axis. As noted above the value of the exploitation rate after removing the fishery regulations is highly uncertain, and the estimate based on the creel census is unreliable (Section IV.B).

IV.C.3. In Section D.3.c and Exhibits E and F, the Bennett report describes the decline in average length (Exhibit E) and weight (Exhibit F) of a cohort as fishing increases, both with and without the current size limit. The average sizes of the fish in a cohort are smaller without the size limit, as expected.

IV.C.4 In Section D.3.d and Exhibit G, the Bennett report describes the effects of increasing exploitation on Spawning Potential Ratio. This calculation is relevant to the question of the eventual equilibrium recruitment because the Spawning Potential Ratio (SPR) is the Lifetime Egg Production (LEP) divided by the LEP with no fishing. Thus it is the fraction of natural replacement that remains in the population fished at a specified exploitation rate. As seen in Exhibit G, SPR declines more rapidly with no size limit because fishing begins at a younger age and smaller size. The value of exploitation rate is highly uncertain because we do not know the response of fishermen to the removal of regulations. The report uses the level of exploitation of 30% here, which is based on their analysis of removing the creel limit which is only a poorly supported estimate of what the catches from 1976 to 2008 would have been, not what they would be in the future, with the removal of the creel limit and the size limit.

IV.D. *Modeled Effects of Eliminating Size and Creel Limits.* In Section D.4 of the Bennett report the exploitation rate of age 2 and 3 striped bass is declared to be 17% and the exploitation rate for ages 3 and older is declared to be about 30%. The source of the former number is not given, and the latter is the figure used earlier as a result from the questionable analysis of creel data, as described in Section IV.B above.

These questionable mortality rates are placed in the simulation model I described above in Section IV.A. As noted there, this model represents the survival from eggs to age 1 recruitment incorrectly. The model does not include the change in that survival with density, nor does it include changes in the amount of fishing as the abundance changes.

IV.E. *Fishery Equilibrium*. In Section D.5 of the Bennett report, the conclusion is drawn that: "At about a 60-70% overall population decrease, the resulting CPUE would be similar to the current CPUE, so the striped bass population would reach a lower equilibrium, subject to other environmental factors." No support or rationale is given for declaring that the equilibrium should occur when the new CPUE equals the old CPUE. Also, no formula or table or other source is given as the basis for the values "60-70%." Furthermore, the term "population" is ambiguous; it is not clear whether this refers to a decline in population abundance, population biomass, population recruitment or some other measure of the population. I note that if catch were expressed in terms of numbers, since CPUE is usually proportional to abundance, the statement that the CPUE would be the same before and after the removal of regulations implies that the abundances would be the same before and after the removal of regulations.

V. Bennett's Conclusions. Section 4G of theBennett report states that his judgement is based on numerous sources of information, and he lists them. He then states that "All of these sources lead to the conclusion that ...". From my analyses it is clear that none of the modeling analyses lead to the conclusion that the striped bass population will decline by 60-70%. Furthermore, such a decline cannot be precisely predicted because of the inherent uncertainty in the stock-recruitment relationship at low abundance and the future behavior of fishermen if the regulations were removed.

References

Botsford, L.W. 1997. Dynamics of populations with density-dependent recruitment and age structure. Chapter 12 in S. Tuljapurkar and H. Caswell (eds.) Structured Population Models in Marine, Terrestrial, and Freshwater Systems. Chapman and Hall, New York.

CDF&G 2009. Striped Bass Creel Census Instructions. California Department of Fish and Game. Xx pp.

Claramunt, R.M., T.L. Kolb, D.F. Clapp, D.B. Hayes, J.L. Dexter Jr. and D.MM. Warner. 2009. Effects of increasing Chinook salmon bag limits on alewife abundance: implications for Lake Michigan management goals. North American Journal of Fisheries Management 29: 829-842.

Email from plaintiff dated ?

Leet, W.S., C.M. Dewees, R. Klingbeil, E.J. Larson (editors). 2001. California's Living Marine Resources: A Status Report. California Department of Fish and Game: Sacramento. 593 pp.

Mace, P.M. and M.P. Sissenwine. 1993. How much spawning per recruit is enough? P. 101-118. In S.J. Smith, J.J. Hunt and D. Rivard [ed.} Risk evaluation and biological reference points for fisheries management. Can Spec. Publ. Fish. Aquat. Sci. 120.

Myers, F.A., K.G. Bowen and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56: 2404-2419.

O'Farrell, M.R. and L.W. Botsford. 2005. Estimation of change in lifetime egg production from length frequency data. Canadian Journal of Fisheries and Aquatic Sciences 62: 1626-1639.

O'Farrell, M. R. and L. W. Botsford. 2006. Estimating the status of nearshore rockfish (*Sebastes spp.*) with length frequency data. Ecological Applications 16: 977-986.

Ralston, S. 2002. West coast groundfish harvest policy. North American Journal of Fisheries Management 22: 249-250.

Restrepo, B.R., G.G. Thompson, P.M. Mace, W.L. Gabriel, L.L. Low, A.D. MacCall, R.D. Methot, J.I. Powers, B.L. Taylor, P.R. Wade and J.F. Witzig. 1997. Technical guidance on the use of precautionary approaches to implementing national standard 1 of the Magnuson -Stevens fishery conservation and management act. NOAA Technical Memorandum NMFS-F/SPO-31.

Sissenwine M.P. and Shepherd, J.G. 1987. An alternative perspective on recruitment overfishing and biological reference points. Canadian Journal of Fisheries and Aquatic Science 44:913-918.

List of other cases:

I have neither testified nor given a deposition in any other cases.

Compensation:

I am being compensated at a rate of $200 per hour for review and consultation, $250 per hour for deposition, arbitration and/or trial testimony, $100 per hour for travel, plus out-of –pocket expenses.

Signature of author:

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Exhibit A

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Education

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Publications

1. 1974 Botsford, L. W., H. E. Rauch, and R. A. Shleser. Optimal temperature control of a lobster plant. IEEE Transactions on Automatic Control AC-19(5):541-542.

2. 1974 Botsford, L.W, H. E. Rauch, and R. A. Shleser. Application of optimization theory to the economics of aquaculture. Proceedings of the Fifth Annual Workshop, World Mariculture Society 5:387-401.

3. 1975 Rauch, H. E., L.W. Botsford, and R. A. Shleser. Economic optimization of an aquaculture facility. IEEE Transactions on Automatic Control AC-20(3):310-319.

4. 1975 Botsford, L.W and D. E. Wickham. Correlation of upwelling index and Dungeness crab catch. US Fishery Bulletin 73(4): 901-907.

5. 1975 Botsford, L.W, H. E. Rauch, A. M. Schuur, and R. A. Shleser. An economically optimum aquaculture facility. Proceedings of the Sixth Annual Workshop, World Mariculture Society 6:407-420.

6. 1977 Botsford, L.W. Current economic status of lobster culture research. Proceedings of the Eighth Annual Workshop, World Mariculture Society 8:723-739.

7. 1978 Botsford, L.W and T. W. Gossard. Implications of growth and metabolic rates on costs of aquaculture. Proceedings of the Ninth Annual Workshop, World Mariculture Society 9:413-423.

8. 1978 Botsford, L.W and D. E. Wickham. Behavior of age-specific, density-dependent models and the Northern California Dungeness crab (*Cancer magister*) fishery. Journal of the Fisheries Research Board of Canada 35:833-843.

9. 1979 Botsford, L.W and D. E. Wickham. Population cycles caused by inter-age density-dependent mortality in young fish and crustaceans. Pp. 73-82 in Cyclic Phenomena in Marine Plants and Animals. E. Naylor and R. G. Hartnoll, Editors.

10. 1981 Botsford, L.W. The effects of increased individual growth rates on depressed population size. American Naturalist 117(1):38-63.

11. 1981 Botsford, L.W. More realistic fishery models: Cycles, collapse, and optimal policy. Pp. 6-20 in Renewable Resource Management. T. L. Vincent and J. Skowronski, Editors.

12. 1981 Botsford, L.W. Optimal fishery policy for size-specific, density-dependent population models. Journal of Mathematical Biology 12:256-293.

13. 1981 Botsford, L.W. Comment on cycles in the Northern California Dungeness crab population. Canadian Journal of Fisheries and Aquatic Sciences 38(10):1295-1296.

14. 1982 Methot, R. D., Jr., and L.W. Botsford. Estimated preseason abundance in the California Dungeness crab (*Cancer magister*) fisheries. Canadian Journal of Fisheries and Aquatic Sciences 39(8):1077-1083.

15. 1982 Botsford, L.W, R. D. Methot, Jr., and J. E. Wilen. Cyclic covariation in the California king salmon, *Oncorhynchus tshawytscha*, silver salmon, *O. kisutch*, and Dungeness crab, *Cancer magister*, fisheries. Fishery Bulletin 80(4):791-801.

16. 1983 Botsford, L.W, R. D. Methot, Jr., and W. E. Johnston. Effort dynamics of the Northern California Dungeness crab (*Cancer magister*) fishery. Canadian Journal of Fisheries and Aquatic Sciences 40(3):337-346.

17. 1983 Botsford, L.W. Age- and size-specific models in the Dungeness crab fishery. In Population Biology Proceedings, Edmonton 1982. Lecture Notes in Biomathematics, No. 52. H. F. Freedman, C. Strobeck, Editors.

18. 1984 Botsford, L.W. Effect of individual growth rates on expected behavior of the Northern California Dungeness crab (*Cancer magister*) fishery. Canadian Journal of Fisheries and Aquatic Sciences 41(1):99-107.

19. 1984 Botsford, L.W and R. Hobbs. Optimal fishery policy with artificial enhancement through stocking: California's white sturgeon as an example. Ecological Modelling 23:293-312.

20. 1984 Allen, P. G., L.W. Botsford, A. M. Schuur, and W. E. Johnston. Bioeconomics of Aquaculture. 351 pp.

21. 1984 Botsford, L.W. Comments on marine survival of Pacific salmonids. Pp. 183-186 in The Influence of Ocean Conditions on the Production of Salmonids in the North Pacific. W. G. Pearcy, Editor. Oregon State University, Corvallis. 327 pp.

22. 1985 Botsford, L.W and T. C. Wainwright. Optimal fishery policy: An equilibrium solution with irreversible investment. Journal of Mathematical Biology 21:317-327.

23. 1985 Wainwright, T. C., R. G. Kope, and L.W. Botsford. Implications of laboratory mosquitofish experiments for population development in rice fields. Proceedings and Papers of the Fifty-Second Annual Conference of the California Mosquito Vector Control Association 52:110-114.

24. 1985 Anderson, S. L., L.W. Botsford, and W. H. Clark, Jr. Size distribution and sex ratios of ridgeback prawns (*Sicyonia ingentis*) in the Santa Barbara Channel (1979-1981). CalCOFI Reports XXVI:169-174.

25. 1985 Botsford, L.W. Models of growth. Pp. 171-188 in Factors in Adult Growth. A. M. Wenner, Editor.

26. 1985 Sykes, S. D., and L.W. Botsford. Chinook salmon, (*Oncorhynchus tshawytscha*) escapement based on multiple mark-recapture of carcasses. Fishery Bulletin 84(2):261-270.

27. 1986 Botsford, L.W. Population dynamics of the Dungeness crab (*Cancer magister*). Canadian Special Publication of Fisheries and Aquatic Sciences 92:140-153.

28. 1986 Johnson, D. F., L.W. Botsford, R. D. Methot, Jr., and T. C. Wainwright. Wind stress and cycles in Dungeness crab (*Cancer magister*) catch off California, Oregon, and Washington. Canadian Journal of Fisheries and Aquatic Sciences 43(4):838-845.

29. 1986 Botsford, L.W and R. C. Hobbs. 1986. Static optimization of yield per recruit with reproduction and fishing costs. Fisheries Research 4:181-189.

30. 1986 Hamilton, A., L.W. Botsford, and J. R. Carey. Demographic examination of sex ratio in the two-spotted spider mite, *Tetranychus urticae* Koch. Entomologia Experimentalis et Applicata 41:147-151.

31. 1986 Botsford, L.W. Effects of environmental forcing on age-structured populations: Northern California Dungeness crab (*Cancer magister*) as an example. Canadian Journal of Fisheries and Aquatic Sciences 43:2345-2352.

32. 1987 Botsford, L.W. Analysis of environmental influences on population dynamics. Pp. 54-64 in Modeling and Management of Resources Under Uncertainty. T. L. Vincent, Y. Cohen, W. J. Grantham, G. P. Kirkwood and J. M. Skowronski, Editors.

33. 1987 Botsford, L.W, B. Vondracek, T. C. Wainwright, A. L. Linden, R. G. Kope, D. E. Reed, and J. J. Cech Jr. Population development of the mosquitofish, *Gambusia affinis*, in rice fields. Environmental Biology of Fishes 20:143-154.

34. 1987 Banks, H. T., L.W. Botsford, F. Kappel, and C. Wang. Modeling and estimation in size structured population models. Pp. 521-541 in Mathematical Ecology. T. G. Hallam, L. J. Gross, and S. A. Levin, Editors.

35. 1988 Botsford, L.W, T. C. Wainwright, J. T. Smith, S. Mastrup, and D. F. Lott. Population dynamics of California quail related to meteorological conditions. Journal of Wildlife Management 52(3):469-477.

36. 1988 Kope, R. G., and L.W. Botsford. Detection of environmental influence on recruitment using abundance data. Canadian Journal of Fisheries and Aquatic Sciences 45:1448-1458.

37. 1989 Botsford, L.W, D. A. Armstrong, and J. M. Shenker. Oceanographic influences on the dynamics of commercially fished populations. Pp. 511-565 in Coastal Oceanography of Washington and Oregon. M. R. Landry and B. M. Hickey, Editors.

38. 1989 Hobbs, R. C., and L.W. Botsford. Dynamics of an age-structured prey with density- and predation-dependent recruitment: The Dungeness crab and a nemertean egg predator worm. Theoretical Population Biology 36:1-22.

39. 1990 Kope, R. G., and L.W. Botsford. Determination of factors affecting recruitment of chinook salmon (*Oncorhynchus tshawytscha*) in central California. US Fisheries Bulletin 88:257-269.

40. 1991 Kohlhorst, D. W., L.W. Botsford, J. S. Brennan, and G. M. Cailliet. Aspects of the structure and dynamics of an exploited central California population of white sturgeon (*Acipenser transmontanus*). Pp. 277-294 in Actes du Premier Colloque Internationale sur l'Esturgeon. P. Williot, Editor. Bordeaux, France.

41. 1991 Botsford, L.W. Crustacean egg production and fisheries management. Pp. 379-394 in Crustacean Egg Production. A. M. Wenner, Editor. 401 pp.

42. 1991 Banks, H. T., L.W. Botsford, F. Kappel, and C. Wang. Estimation of growth and survival in size-structured cohort data: An application

to larval striped bass (*Morone saxatilis*). Journal of Mathematical Biology 30:125-150.

43. 1992 Hobbs, R. C., and L.W. Botsford. Diel vertical migration and timing of metamorphosis of larval Dungeness crab *Cancer magister*. Marine Biology 112:417-428.

44. 1992 Botsford, L.W. Further analysis of Clark's delayed recruitment model. Bulletin of Mathematical Biology 54:275-293.

45. 1992 Hobbs, R. C., L.W. Botsford, and R. G. Kope. Bioeconomic evaluation of the culture/stocking concept for California halibut. Pp. 417-449 in The California Halibut, *Paralichthys californicus*, Resources and Fisheries. C. W. Haugen, Editor. California Department of Fish & Game Fish Bulletin #174.

46. 1992 Botsford, L.W. Individual state structure in population models. Chapter 10, pp 213-236 in Individual-Based Approaches in Ecology: Concepts and Models. D. DeAngelis and L. Gross, Editors. 525 pp.

47. 1992 Botsford, L.W and J. G. Brittnacher. Detection of environmental influences on wildlife populations: California quail as an example. Pp. 158-169 in Wildlife 2001: Populations. D. R. McCulloch and R. Barrett, Editors. 1163 pp.

48. 1992 Jain, S. K., and L.W. Botsford, Editors. Applied Population Biology. 295 pp.

49. 1992 Botsford, L.W and S. K. Jain. Population biology and its application to practical problems. Pp. 1-24 in Applied Population Biology. S. K. Jain and L. W. Botsford, Editors. 295 pp.

50. 1992 Botsford, L.W and S. K. Jain. Applying the principles of population biology: Assessment and recommendations. Pp. 263-286 in Applied Population Biology. S. K. Jain and L. W. Botsford, Editors. 295 pp.

51. 1992 Hobbs, R. C., L.W. Botsford, and A. Thomas. Influence of hydrographic conditions and wind forcing on the distribution and abundance of Dungeness crab, *Cancer magister*, larvae. Canadian Journal of Fisheries and Aquatic Sciences 49:1379-1388.

52. 1994 Botsford, L.W, B. D. Smith, and J. F. Quinn. Bimodality in size distributions: The red sea urchin *Strongylocentrotus franciscanus*. Ecological Applications 4(1):42-50.

53. 1994 Quinn, J. F., S. R. Wing, and L.W. Botsford. Harvest regufia in marine invertebrate fisheries: Models and applications to the red sea urchin *Strongylocentrotus franciscanus*. American Zoologist 33:537-550.

54. 1994 Botsford, L.W, C. L. Moloney, A. Hastings, J. L. Largier, T. M. Powell, K. Higgins, and J. F. Quinn. The influence of spatially and temporally varying oceanographic conditions on meroplanktonic metapopulations. Deep-Sea Research II 41:107-145.

55. 1994 Botsford, L.W, J. F. Quinn, S. R. Wing, and J. G. Brittnacher. Rotating spatial harvest of a benthic invertebrate, the red sea urchin, *Strongylocentrotus franciscanus*. Pp. 409-428 in Proceedings, International Symposium on Management Strategies for Exploited Fish Populations, Alaska Sea Grant College Program, #AK-93-02.

56. 1994 Botsford, L.W. Extinction probabilities and delisting criteria for Pacific salmonids. Conservation Biology 8:873-875.

57. 1994 Botsford, L.W, D. F. Lott, J. G. Brittnacher, and S. Mastrup. Effects of precipitation and density on the abundance of California quail on Santa Cruz Island. Pp. 401-405 in Proceedings, The Fourth California Islands Symposium: Update on the Status of Resources. Halvorson, W. L. and G. J. Maender, Editors. Santa Barbara Museum of Natural History, Santa Barbara, CA.

58. 1995 Botsford, L.W. Population dynamics of spatially distributed, meroplanktonic, exploited marine invertebrates. ICES Marine Science Symposium 199:118-128.

59. 1995 Botsford, L.W and R. C. Hobbs. Recent advances in the understanding of cyclic behavior of Dungeness crab (*Cancer magister*) populations. ICES Marine Sciences Symposium 199:157-166.

60. 1994 Moloney, C. L., L.W. Botsford, and J. L. Largier. Development, survival and timing of metamorphosis of planktonic larvae in a variable environment: the Dungeness crab as an example. Marine Ecology Progress Series 113: 61-79.

61. 1995 Wing, S. R., J. L. Largier, L.W. Botsford, and J. F. Quinn. Settlement and transport of benthic invertebrates in an intermittent upwelling region. Limnology and Oceanography 40: 316-329.

62. 1995 Wing, S. R., L.W. Botsford, J. L. Largier, and L. E. Morgan. Spatial structure of relaxation events and crab settlement in the northern California upwelling region. Marine Ecology Progress Series 128: 199-211.

63. 1996 Cailliet, G. M., L.W. Botsford, J. G. Brittnacher, G. Ford, M. Matsubayashi, A. King, D. L. Waters, and R. G. Kope. Development of a computer-aided age determination system: Evaluation based on otoliths of bank rockfish off California. Transactions of the American Fisheries Society 125:874-888.

64. 1997 Botsford, L.W. Dynamics of populations with density-dependent recruitment and age structure. Chapter 12 in S. Tuljapurkar and H. Caswell (eds.) Structured Population Models in Marine, Terrestrial, and Freshwater Systems. Chapman and Hall, New York.

65. 1997 Higgins, K., A. Hastings, and L.W. Botsford. Density dependence and age structure: nonlinear dynamics and population behavior. American Naturalist, Vol. 149, No. 2.

66. 1997 Higgins, K., A. Hastings, J. N. Sarvela, and L.W. Botsford. Stochastic dynamics and deterministic skeletons: Population behavior of Dungeness crab. Science 276:1431-1435.

67. 1997 Botsford, L.W, J. C. Castilla, and C. H. Peterson. The management of fisheries and marine ecosystems. Science 277:509-515.

68. 1997 Botsford, L.W. Human activities, climate changes affect marine populations. California Agriculture 51:36-44.

69. 1997 Cisneros-Mata, M. A., L.W. Botsford, and J. F. Quinn. Projecting viability of *Totoaba macdonaldi*, a population with unknown age-dependent variability. Ecological Applications 7:968-980.

70. 1997 Botsford, L.W, and J. G. Brittnacher. Viability of Sacramento River Winter-Run Chinook Salmon. Conservation Biology 12(1):65-79.

71 1998 Smith, B. D., L.W. Botsford, and S. R. Wing. Estimation of growth and mortality parameters from size frequency distributions lacking age patterns: the red sea urchin (Strongylocentrotus franciscanus) as an example. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 55, No. 5, pp. 1236-1247.

72 1998 Smith, B. D. and L.W. Botsford. Interpretation of growth, mortality, and recruitment patterns in size-at-age, growth, increment, and size

frequency data. *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. *Edited by* G. S. Jamieson and A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci. 125:125-139.

73 1998 Wing, S. R., L.W. Botsford, and J. F. Quinn. The impact of coastal circulation on the spatial distribution of invertebrate recruitment, with implications for management. *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. *Edited by* G. S. Jamieson and A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci. 125:285-294.

74. 1998 Botsford, L.W., C. L. Moloney, J. L. Largier, and A. Hastings. Metapopulation dynamics of meroplanktonic invertebrates: the Dungeness crab (*Cancer magister*) as an example. *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. *Edited by* G. S. Jamieson and A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci. 125:295-306.

75. 1998 Wing, S. R., L.W. Botsford, S. V. Ralston, and J. L. Largier. Meroplanktonic distribution and circulation in a coastal retention zone of the northern California upwelling system. Limnol. Oceanogr. 43(7):1710-1721.

76. 1998 Botsford, L.W., S.R. Wing and J.L. Largier. Population dynamics and management implications of larval dispersal. S. Afr. J. mar. Sci. 19: 131-142.

77. 1998 Wing, S.R., J.L. Largier, and L.W. Botsford. Coastal retention and onshore transport of meroplankton near capes in eastern boundary currents: examples from the California Current. S. Afr. J. mar. Sci. 19: 119-127.

78. 1999 Hastings, A. and L.W. Botsford. Equivalence in yield from marine reserves and traditional fisheries management. Science 284: 1537-1538.

79. 1999 Botsford, L.W., L.E. Morgan, D.R. Lockwood, and J.E. Wilen. Marine reserves and management of the northern California red sea urchin fishery. CalCOFI Rep. 40: 87-93.

80. 1999 Murray, S.N., R.F. Ambrose, J.A. Bohnsack, L.W. Botsford, M.H. Carr, G.E. Davis, P.K. Dayton, D. Gotshall, D.R. Gunderson, M.A. Hixon, J. Lubchenco, M. Mangel, A. MacCall, D. A. Mc Ardle, J.C. Ogden, J. Roughgarden, R.M. Starr, M.J. Tegner, and M.M. Yoklavich. No-take

reserve networks: sustaining fishery populations and marine ecosystems.Fisheries 24: 11-25.

81. 1999 Morgan, L.E., L.W. Botsford, C.J. Lundquist and J.F. Quinn. The potential of no-take reserves to sustain the red sea urchin (Strongylocentrotus franciscanus) fishery in northern California. Bull Tohoku Natl. Fish. Res. Inst. 62: 83-94.

82. 2000 Botsford, L.W. and C.M. Paulsen. Assessing covariability among populations in the presence of intraseries correlation: Columbia River spring-summer chinook salmon (Oncorhynchus tshawytscha) stocks. Can. J. Fish. Aquat. Sci 57: 616-627.

83. 2000 Morgan, L.E., S.R.Wing, L.W. Botsford, C.J. Lundquist and J.M. Diehl. Spatial variability in red sea urchin (Strongylocentrotus franciscanus) recruitment in northern California. Fisheries Oceanography 9: 83-98.

84. 2000 Morgan, L.E., L.W. Botsford, S.R. Wing and B.D. Smith. Spatial variability in growth and mortality of the red sea urchin, Strongylocentrotus franciscanus in northern California. Can. J. Fish Aquat. Sci. 57: 980-992.

85. 2000 Lundquist, C.J., L.W. Botsford, L.E. Morgan, J.M. Diehl, T. Lee, D.R. Lockwood and E.L. Pearson. Effects of El Niño and La Niña on local invertebrate settlement in northern California. Cal COFI Rep. 41: 167-176.

86. 2000 Agrawal, AA; Rudgers, JA; Botsford, LW; Cutler, D; Gorin, JB; Lundquist, CJ; Spitzer, BW, Swann, AL. 2000. Benefits and constraints on plant defense against herbivores: Spines influence the legitimate and illegitimate flower visitors of yellow star thistle Centaurea solstitialis L-(asteraceae). Southwestern Naturalist 45: 1-5.

87. 2001 Botsford, L.W., Hastings, A., and Gaines, S.D. Dependence of sustainability on the configuration of marine reserves and larval dispersal distance Ecology Letters 4: 144-150.

88. 2001 Botsford, LW. Physical influences on recruitment to California Current invertebrate populations on multiple scales. ICES Journal of Marine Science 58:1081-1091.

89. 2001 Jackson, JBC; Kirby, MX; Berger, WH; Bjorndal, KA; Botsford, LW; Bourque, BJ; Bradbury, RH; Cooke, R; Erlandson, J; Estes, JA; Hughes, TP; Kidwell, S; Lange, CB; Lenihan, HS; Pandolfi, JM;

Peterson, CH; Steneck, RS; Tegner, MJ; Warner, RR. Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629-638.

90. 2001 Morgan, L.E. and L.W. Botsford. Managing with reserves: modeling uncertainty in larval dispersal for a sea urchin fishery. Pp. 667-684 in Proceedings of the Symposium on Spatial Processes and Management of Marine Populations, University of Alaska Sea Grant, 720 pp.

91. 2002 Lundquist, C.J., J.M. Diehl, E. Harvey and L.W. Botsford. Factors affecting implementation of recovery plans. Ecological Applications 12: 713-718.

92. 2002 Weinberg, M; Lawrence, CA; Anderson, JD; Randall, JR; Botsford, LW; Loeb, CJ; Tadokoro, CS; Orlob, GT; Sabatier, P. Biological and economic implications of Sacramento watershed management options. Journal of the American Water Resources Association, 38:367-384.

93. 2002 Botsford, L.W. and C. A. Lawrence. Patterns of co-variability among California current chinook salmon, coho salmon, Dungeness crab, and physical oceanographic conditions. Progress in Oceanography 53: 283-305.

94. 2002 Lockwood, D.L., A. Hastings and L.W. Botsford.. The effects of dispersal patterns on marine reserves: does the tail wag the dog? Theoretical Population Biology 61: 297-309.

95. 2002 N.L. Andrew, Y. Agatsuma; E. Ballesteros, A.G. Bazhin, E.P. Creaser, D.K.A. Barnes, L.W. Botsford, A. Bradbury, A. Campbell, J.D. Dixon, S. Einarsson, P. Gerring, K. Hebert, M. Hunter, S.B. Hur, C.R. Johnson, M.A. Juinio-Meñez, P. Kalvass, R.J. Miller, C.A. Moreno, J.S. Palleiro, D. Rivas, S.M.L. Robinson, S.C. Schroeter, R.S. Steneck, R.I. Vadas, D.A. Woodby and Z. Xiaoqi . Status and management of world sea urchin fisheries. Oceanogr. Mar. Biol. Annu. Rev. 40: 343-425.

96. 2002 Wilen, J.E., M.D. Smith, D. Lockwood and L.W. Botsford. Avoiding surprises: incorporating fishermen behavior into management models. Bulletin of Marine Science 70: 553-575.

97. 2002 Hill, M.F., A. Hastings and L.W. Botsford. The effects of small dispersal rates on extinction times in structured metapopulation models. American Naturalist 160: 389-402.

98. 2002 Batchelder, H.P., J.A. Barth, P. M. Kosro, P.T. Strub, R.D. Brodeur, W.T. Peterson, C.T. Tynan, M.D. Ohman, L.W. Botsford, T. M. Powell, F.B. Schwing, D.G. Ainley, D.L. Mackas, B.M. Hickey and S. R. Ramp. The GLOBEC Northeast Pacific California Current System Program. Oceanography 15: 36-47.

99. 2002 Botsford, L.W., C.A. Lawrence, M.F. Hill, A. Hastings and K.S. McCann. Dynamic response of California Current populations to environmental variability. In N. McGinn, (ed.) AFS Symposium: Fisheries in a Changing Climate 32: 215-226.

100. 2003 Hastings, A. and L.W. Botsford. Are marine reserves for fisheries and biodiversity compatible? Ecological Applications 13: S65-S70.

101. 2003 Gerber, L.R., S.J. Andelman, L.W. Botsford, S.D. Gaines, A. Hastings, S.R. Palumbi and H.P. Possingham. Population models for marine reserve design: A retrospective and prospective synthesis. Ecological Applications 13: S47-S64.

102. 2003 Botsford, L.W., F. Micheli and A. Hastings. Principles for the design of marine reserves. Ecological Applications 13: S25-S31.

103. 2003. Botsford, L.W., C.A. Lawrence, E.P. Dever, A. Hastings and J. Largier. Wind strength and biological productivity in upwelling systems. Fisheries Oceanography 12: 1-15.

104. 2003 Hill, M.F., LW. Botsford, and A. Hastings. The effects of spawning age distribution on salmon persistence in fluctuating environments. Journal of Animal Ecology 72: 732-744.

105. 2003 Wing, S.R., L.W. Botsford, L.E. Morgan, J.M. Diehl and C.J. Lundquist. 2003. Inter-annual variability in larval supply to populations of three invertebrate
\859-872.

106. 2003 McCann, K.S, L.W. Botsford and A. Hastings. Differential response of marine populations to climate forcing. Canadian Journal of Fisheries and Aquatic Sciences 60: 971-985.

107. 2004 Botsford, L.W., D. M. Kaplan and A. Hastings. Sustainability and yield in marine reserve policy. American Fisheries Society Symposium 42: 75-86.

108. 2004 Hilborn, R., K. Stokes, J-J. Maguire, T. Smith, L.W. Botsford, M. Mangel, J. Orensanz, A. Parma, J. Rice, J. Bell, K.L. Cochrane, S.

Garcia, S.J. Hall, G.P. Kirkwood, K. Sainsbury, G. Stefansson and C. Walters. When can marine reserves improve fisheries management? Ocean and Coastal Management 47: 197-205.

109. 2004 Lundquist, C.J. and L.W. Botsford.. Model projections of the fishery implications of the Allee effect in broadcast spawners. Ecological Applications 14: 929-941.

110. 2004 Botsford, L.W., A. Campbell and R. Miller. Biological reference points in the management of north American sea urchin fisheries. Canadian Journal of Fisheries and Aquatic Sciences 61: 1325-1327.

111. 2004 Micheli, F., B.S. Halpern, L.W. Botsford and R.R. Warner. Trajectories and correlates of community change in no-take marine reserves. Ecological Applications 14: 1709-1723.

112. 2005 Botsford, L.W., C.A. Lawrence and M.F. Hill. Differences in dynamic response of California Current salmon species to changes in ocean conditions. Deep-Sea Research II: 52: 331-345.

113. 2005 Botsford, L.W. Potential contributions of marine reserves to sustainable fisheries: recent modeling results. Bulletin of Marine Science 76: 245-259.

114. 2005 Kaplan, D.M. and L.W. Botsford. Effects of variability in spacing of coastal marine reserves on fisheries yield and sustainability. Canadian Journal of Fisheries and Aquatic Sciences 62: 905-912.

115. 2005 Botsford, L.W. and A.M. Parma. Uncertainty in marine management. Pp. 375-392 in E. Norse and L.Crowder,(eds). Marine Conservation Biology: the science of maintaining the sea's biodiversity. Island Press, Covelo. 470 pp.

116. 2005 O'Farrell, M.R. and L.W. Botsford. Estimation of change in lifetime egg production from length frequency data. Canadian Journal of Fisheries and Aquatic Sciences 62: 1626-1639.

117. 2005 Kaplan, D.F., J. Largier and L.W. Botsford. HF radar observations of surface circulation off Bodega Bay (Northern California, USA). Journal of Geophysical Research 110: C10020.

118. 2006 Botsford, L.W. and A. Hastings. Conservation dynamics of marine metapopulations with dispersing larvae. Pp. 411-429 and Ch 12 in Marine Metapopulations, edited by P. Sale and J. Kritzer.

119. 2006 Fogarty, M.J. and L. W. Botsford. Metapopulation dynamics of coastal decapods. Pp 271-319 and Chapter 8 in Marine Metapopulations, edited by P. Sale and J. Kritzer.

120. 2006+ Hastings, A. and L.W. Botsford. Persistence of spatial populations depends on returning home. Proceedings of the National Academy of Sciences, U.S. 103: 6067-6072.

121. 2006 Hastings, A. and L.W. Botsford. A simple persistence condition for structured populations. Ecology Letters 9: 846-852.

122. 2006 O'Farrell, M. R. and L. W. Botsford. Estimating the status of nearshore rockfish (*Sebastes spp.*) with length frequency data. Ecological Applications 16: 977-986.

123. 2006 O'Farrell, M. R. and L. W. Botsford The fisheries management implications of maternal-age-dependent larval survival. Canadian Journal of Fisheries and Aquatic Sciences 63: 2249-2258.

124. 2006+ Kaplan, D.M., L.W. Botsford and S. Jorgensen. Dispersal per recruit: an efficient method for assessing sustainability in marine reserve networks. Ecological Applications 16: 2248-2263.

125. 2006 Jorgensen, S.J., D.M. Kaplan, A.P. Klimley, S.G. Morgan, M.R. O'Farrell and L. W. Botsford. Limited movement in blue rockfish (Sebastes mystinus): internal structure of the home range. Marine Ecology Progress Series 327:157-170.

126. 2006 Botsford, L.W., C.A. Lawrence, E.P. Dever, A. Hastings and J. Largier. Effects of variable winds on biological productivity on continental shelves in coastal upwelling systems. Deep Sea Research II 53: 3116-3140.

127. 2006 Largier JL, CA Lawrence, M Roughan, DM Kaplan, EP Dever, CE Dorman, RM Kudela, SM Bollens, FP Wilkerson, RC Dugdale, LW Botsford, N Garfield, B Kuebel-Cervantes, D Koracin. WEST: a northern California study of the role of wind-driven transport in the productivity of coastal plankton communities. Deep Sea Research II 53: 2833-2849.

128. 2006 Dawson, MN, RK Grosberg and LW Botsford. Connectivity in marine protected areas. Science 313: 43-44.

129. 2007 Botsford, L.W., F. Micheli and A.M. Parma. Biological and ecological considerations in the design, implementation and success of MPAs. Pp. 109-148 in Expert Workshop on Marine Protected Areas and Fisheries

Management: Review of Issues and Considerations, FAO Fisheries Report No. 825, Rome, Italy. 332 pp.

130. 2007 Fogarty, M.J. and L.W. Botsford. Population connectivity and spatial management of marine fisheries. Oceanography 20:.112-123.

131. 2007 Adams, P.B., L.W. Botsford, K.W. Gobalet, R.A. Leidy, D.R. McEwan, P.B. Moyle, J.J. Smith, J.G. Williams, and R.M. Yoshiyama. Coho salmon are native south of San Francisco Bay: A reexamination of North American coho salmon's southern range limit. Fisheries 32: 441-451.

132. 2007 Diehl, J.M., R.J. Toonen, and L.W. Botsford. Variabilty in the spatial pattern of recruitment of the sand crab, *Emerita analoga*, throughout California in relation to wind-driven currents. Marine Ecology Progress Series 350: 1-17.

133. 2008 Botsford, L.W., D.R. Brumbaugh, C. Grimes, J.B. Kellner, J. Largier, M.R. O'Farrell, S. Ralston, E. Soulanille and V. Wepestad. Connectivity, sustainability and yield: bridging the gap between conventional fishery management and marine protected areas. Reviews in Fish Biology and Fisheries 19: 69-95.

134. 2009 Kaplan, D.M., L.W. Botsford, S. D. Gaines and S.J. Jorgensen. Model-based assessment of persistence in proposed marine protected area designs for the central California coast. Ecological Applications 19: 433-448.

135. 2009 Botsford, L.W., J.W. White, M.-A. Coffroth, C.B. Paris, S. Planes, T.L. Shearer, S.R. Thorrold, G.P. Jones. Connectivity and resilience of coral reef metapopulations in MPAs: matching empirical efforts to predictive needs. Coral Reefs 28: 327-337.

136. 2009 Yokomizo, H., L.W. Botsford, M.D. Holland, C.A. Lawrence and A. Hastings. Optimal wind patterns for biological production in shelf ecosystems driven by coastal upwelling. Theoretical Ecology. DOI 10.1007/s12080-009-0053-5

137. 2009 Moffitt, E.A., L.W. Botsford, D.M. Kaplan and M.R. O'Farrell. Marine reserve networks for species that move within a home range. Ecological Applications 19: 1835-1847.