

Fig.12. Immature predator biomass extinct to reach MSTY at $e_1 = 1.003$ and $e_3 = 0.33$.

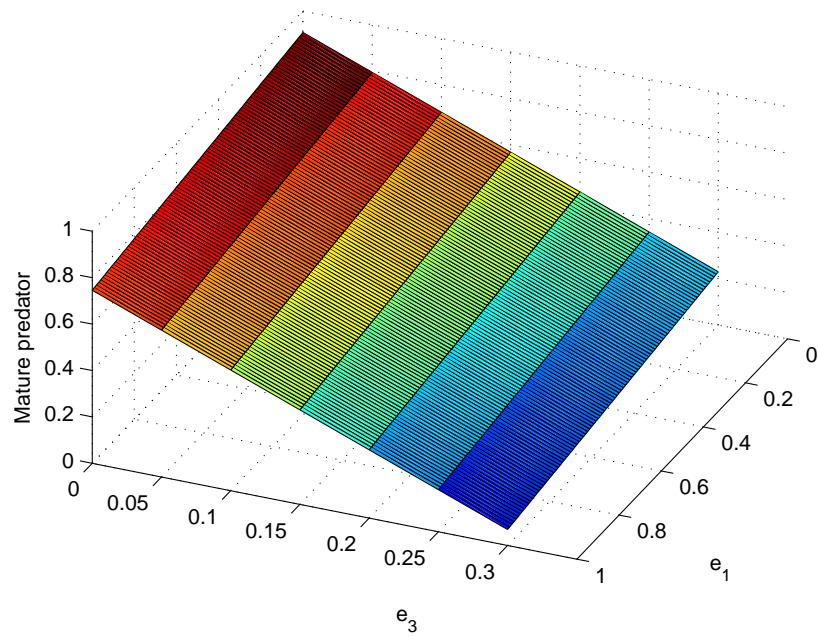


Fig.13. Mature predator biomass extinct to reach MSTY at $e_1 = 1.003$ and $e_3 = 0.33$.

6 Conclusion

This article describes the impacts of harvesting to reach the MSY or MSTY level in a stage structured population model. Some of the results are derived analytically and some others are shown numerically using the simulated parameter sets. It is observed that if prey is the only target species for harvesting, then MSY always exists. In this situation prey biomass reduces to exactly half of its value

in compared to unexploited system. Legovic et al. (2010) showed that in traditional prey predator systems, fishing to reach MSY of the prey population only will cause the extinction of predator population but in this case it is a sustainable policy (see Fig.1). It is also shown that harvesting the mature predator to reach MSY is a sustainable policy but predator biomass reduces exactly half of the unexploited system. One of our important investigation is to reach MSTY when combined harvesting effort is imposed to the prey and the mature predator. We have analyzed the impacts of common harvesting effort analytically and also illustrated numerically. It is observed that MSTY may exist (see Fig.3), and if it dose not exist then it is due to extinction of either the predator (see Fig.4.), or prey species (see Fig.5).

Lastly, we have discussed about the global MSTY taking independent harvesting efforts. It is seen that if global MSTY exists, it is independent of catchability coefficients. This result is a great achievement for a stage structured population model. Fig. 3 shows that MSTY under combined harvesting effort exists and is equal to 1.399 where as the same system exhibits the result that the global MSTY if exists is equal to 1.42 which is larger than MSTY under combined harvesting effort. In another simulation it is proved that though Hessian Matrix with respect to the selective harvesting effort is negative definite i.e., necessary condition for global MSTY is satisfied but due to extinction of predators species global MSTY does not occur for harvesting the prey and mature predator.

Acknowledgment

Prosenjit Paul is grateful to University Grants Commission (UGC, File No.: F. 11-2/2002(SA I) dated 2nd December, 2013) for the financial support of this research.

References

1. , W.G. Aiello, H.I. Freedman, J. Wu, Analysis of a model representing stage-structured population growth state-dependent time delay. *SIAM. J. Appl. Math.* 52 (3), 1992.
2. K. Chakraborty, K. Das, T. K. Kar, Combined harvesting of a stage structured prey-predator model incorporate cannibalism in competitive environment, *C. R. Biologies* 336, 34-45, 2013.
3. Ghosh, B., Kar, T. K.: Maximum sustainable yield and species extinction in a preypredator system: some new results. *J Biol Phys.* DOI 10.1007/s10867-013-9303-2, 2013.
4. L. Huimin, The harvesting optimal problem of critical depensation systems. *J. Biomech.* 13(6), 1998.
5. T.K. Kar, Stability and optimal harvesting of a prey predator model with stage-structure for predator, *Applicationes Mathematicae*, 32, 279-291, 2005.
6. T.K. Kar, B. Ghosh, Impacts of maximum sustainable yield policy to prey-predator systems. *Ecol. Model.* 250, 134-142, 2013.
7. T. Legovic, S. Gecek, Impact of maximum sustainable yield on independent populations. *Ecol. Model.* 221, 21082111, 2010.
8. T. Legovic, S. Gecek, Impact of maximum sustainable yield on mutualistic communities. *Ecological Modelling* 230, 6372, 2012.
9. H. Matsuda, P. A. Abrams, Maximal yields from multispecies fisheries systems: Rules for systems with multiple trophic levels. *Ecological Application*, 16, 225-237, 2006.
10. H. Matsuda, P. A. Abrams, Is feedback control effective for ecosystem based fisheries management? *Journal of Theoretical Biology*, 339, 122-128, 2013.
11. F. Meng, W. Ke, Study on harvesting population with diffusional migration, *J. Syst. Sci. Comp.* 14 (2), 2001.
12. F. Meng, W. Ke, Optimal harvesting policy for single population with periodic coefficients, *Math. Biosci.* 152, 1998.
13. J.D. Murray, *Mathematical Biology*, Springer-Verlag, Berlin Heidelberg, New York, 1989.
14. R.M. May, J.R. Beddington, C.W. Clark, S.J. Holt, R.M. Laws, Management of multi species fisheries. *Science*, 205, 267-277, 1979.
15. C.J. Walters, V. Christensen., S.J. Martell, J.F. Kitchell, Possible ecosystem impacts of applying MSY policies from single-species assessment. *ICES J. Marine Sci.* 62, 558-568, 2005.
16. W. Wang, L. Chen, A predator-Prey system with stage structure for predator, *Computer & Mathematics with Applications.* 33(8), 1997.
17. A.A.S. Zaghrou, S.H. Attalah, Analysis of a model of stage-structured population dynamics growth with time state-dependent time delay, *Appl. Math. Comput.* 77, 1996.