Available online at: http://ejournal-balitbang.kkp.go.id/index.php/ifrj
e-mail:ifrj.puslitbangkan@gmail.com
INDONESIAN FISHERIES RESEARCH JOURNAL
Volume 22 Nomor 2 December 2016
p-ISSN: 0853-8980
e-ISSN: 2502-6569
Accreditation Number: 704/AU3/P2MI-LIPI/10/2015

INTER-SPECIFIC COMPETITION AND FISHING EFFECT TO POPULATION DYNAMIC OF BALI SARDINE (*SARDINELLA LEMURU*)

Andhika Prima Prasetyo*[1] and Rudy Masuswo Purwoko[1]
[1]Research Center for Fisheries Research and Development, Jl. Pasir Putih II Ancol Timur, Jakarta. Indonesian
Received; Oct 24-2016 Received in revised from Dec 14-2016; Accepted Dec 16-2016

ABSTRACT

Stock-recruitment relationship of Bali sardine was investigated based on Beverton-Holt model by assuming inter-specific competition. Model is modified to incorporate the effect of fishing pressure that is density-independent to population dynamic by developing scenario fishing on adult and/or juvenile population. The results show that harvested adult the dramatic decline of recruitment supply. However, harvested juvenile is led to the positive response to population size, as an increase in fishing mortality rate will reduce competition mortality rate. Precautionary approach required by considering bipartite life cycle.

Keywords: Stock-recruitment relationship; fishing pressure; Bali Sardine

INTRODUCTION

Bali sardine (*Sardinella lemuru*) is self-contained breading population which is distributed in the high productive waters between Java Island and Bali Island, Indonesia (Bali Strait) (Merta, 1992). The fish is the dominated species in Bali Strait by ±90% of total catch landed (Buchary, 2010). This small pelagic fish is the first consumer in the food chain by considering 90.9% of gut content consist of zooplankton (Setyohadi, 2010). Furthermore, based on their distribution, population of Bali sardine likely divided into two larger age-structured namely juvenile and adult that concentrated in northern part (coastal waters) and southern part of Bali Strait, respectively (Wudianto & Wujdi, 2014). The population dynamic of Bali sardine is mainly influenced by environmental condition, such as Southern Oscillation Index (SOI) and Dipole Mode Index (DMI) (Prasetyo & Natsir, 2010; Puspasari *et al*., 2015).

The exploitation was started in 1980s and dramatically increases the fishing pressure by improving fishing capacity (Merta, 1992; Wujdi *et al*., 2012). Purse seine is the main fishing gear in Bali Strait; however, lift-net also exploited the resources in coastal waters, which is mainly targeted juvenile. In order to ensure the sustainability of fisheries in term of ecology and economic, appropriate management measure is needed. An effective management of exploited populations required essential information on population dynamic such as growth, mortality and maturity (Hilborn & Walters, 1992). However, fisheries are highly uncertainty. Moreover, Hilborn & Walters (1992) stated that "The most important and generally most difficult problem in biological assessment of fisheries is the relationship between stock and recruitment". The lack of knowledge on stock-recruitment relationship likely lead to recruitment over-fishing. Recruitment over-fishing occurred when fishing reduce the size of the adult breeding stock to a point where production of larvae and subsequent recruits is reduce (Hilborn & Walters, 1992). Beverton-Holt model is one of stock-recruitment relationship model and has long been used to study the population dynamics in ecology. It is also known as the Leslie–Gower model that taken into account inter-specific competition among species in the discrete time (Chow & Hsieh, 2013).

This research examines stock-recruitment relationship of Bali Sardine by incorporating fishing pressure in different scenario by modifying Beverton-Holt model. First scenario will assume fishing only presence on adult population. Second scenario will assume both adult and juvenile are vulnerable to fishing. Stability analysis will provide information about equilibrium to identify stable point of population and calculate how harvest influence equilibrium. The condition in respect harvest rate where population is

correspondence author:
e-mail: dhika_fishery@yahoo.com

stable will also examine. This research expects that fishing pressure on adult population will decrease equilibrium value in which population stable. Moreover, juvenile harvest likely will decrease of recruitment, however, less juvenile density probably effect an increase juvenile grow since decline of settlement competition.

MATERIALS AND METHODS

Models

Population dynamic of Bali sardine will be constructed by following process-based models from Beverton-Holt models. Beverton-Holt model chosen by considering cannibalism is minimal and dominated by competition process within juvenile phase (Setyohadi, 2010). The model will be derived into two possible scenarios, namely (a) vulnerability of fishing occurs for adult population only, and (b) both juvenile and adult are exposed by fishing pressure in different levels.

In order to simply the model, Bali sardine followed reasonably assumptions, namely (a) Bali sardine population in Bali Strait is self-breading population, (b) A discrete breading season, (c) Reproductive maturity reached at age 1, (d) Density-independent adult survival, (e) Density-independent fecundity, (f) Density independent larval survival and settlement, (g) Settling larvae compete with one another during the juvenile phase, (h) Cannibalism is minimal, (i) Number of adult changes slowly relative to the number of juveniles, (j) Density-independent harvest rate, and (k) Environment effect is uniform across the Bali Strait – positively correlated.

Beverton-Holt model was used by incorporating harvest variable within discrete time. Originally, Beverton-Holt model assumes inter-specific competition among juvenile as density-dependent function of juvenile density, such as settlement, nesting and feeding. Beverton-Holt model modelled per-capita juvenile mortality as a linearly increasing function of juvenile abundance $\frac{dJ\tau}{d\tau} = \left(-\mu_n - \mu_s J(\tau)\right) J(\tau)$ (Figure 1-Eq. 1). Then, the solution of this differential equation is $J(\tau) = \frac{sfe^{\mu_n \tau}}{1 + \frac{sf\mu_s}{\mu_n}(1 - e^{-\mu_n \tau})Nt} Nt$ .Then, the equation has the density-independent component of per-capita recruitment ($(b = sfe^{-\mu_n \tau})$), and the density-dependent component of per-capita recruitment. $\left(a = \frac{sf\mu_s}{\mu_n}(1 - e^{-\mu_n \tau})\right)$ The Beverton-Holt model become $N_{t+1} = \left[1 - d + \frac{b}{1 + aN_t}\right] N_t$ (Figure 1-Eq. 3) where, J_τ is number of juvenile in time τ in between time at settlement and t+1, μ_n is the per-capita mortality in the absence of density-dependence, μ_s is the per-capita competition among juvenile, s is probability of larval survival (combination between larval survival ($e^{-\mu L}$) and probability of success settlement (Ps)), f is constant for fecundity since fecundity is density-independent, d is constant for death since adult survival is density-independent.

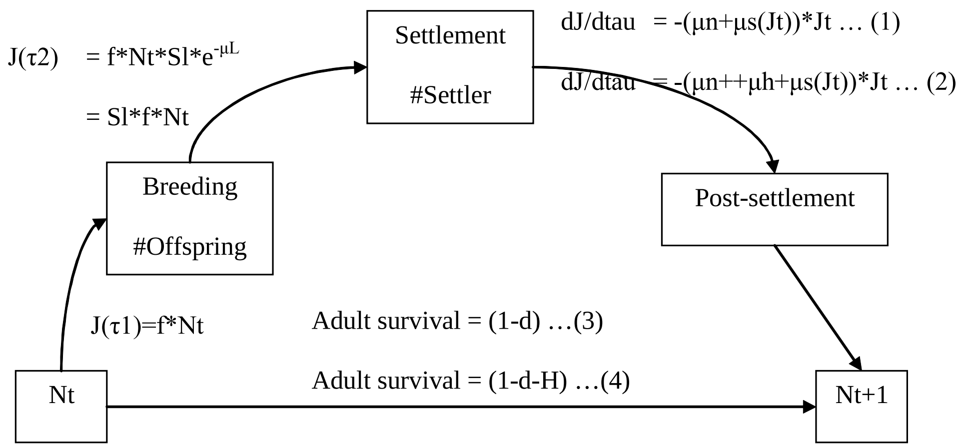

Figure 1. The population dynamic schematic of Bali sardine.

Basic model of Beverton-Holt will be modify based on reasonable assumptions and scenarios. First scenario plugged harvest in adult population using purse seine, where H is proportion of adult harvested (Figure 1-Eq 4). Moreover, adult harvest is density-independent in the discrete time; therefore it will modify the population model as.

$$N_{t+1}\left[1-d-H+\frac{b}{1+aN_t}\right]N_t$$

Moreover, second scenario that fishing is occurred to juvenile and adult population by using lift-net (ì$_h$) and adult population (H). It will modify per-capita juvenile mortality as $\frac{dJ\tau}{d\tau}=(-\mu_n-\mu_s J(\tau)-\mu_n)J(\tau)$ (Figure 1-Eq 2). Then, the solution of this differential equation is $J(t)=\frac{Sf\mu_n e^{-(\mu_n+\mu_h)\tau}+S1f\mu_h e^{-(\mu_n+\mu_h)\tau}}{NtS1f\mu_s(1-e^{-(\mu_n+\mu_h)\tau})+\mu n+\mu h}*Nt$

Then, the equation consists of a density-independent component of per-capita recruitment due to non-fishing $(b=Sf\ \mu_n e^{-(\mu_n+\mu_h)\tau})$, density-independent component of per-capita recruitment due to fishing $(h=Sf\ \mu_h e^{-(\mu_n+\mu_h)\tau})$; total density-independent mortality rate component (Td = $\mu_n + \mu_h$; which is assume as 1/(n+h)), and the density-dependent component of per-capita recruitment $(a=S1f\ \mu_s(1e^{-(\mu_n+\mu_h)\tau}))$.

The Beverton-Holt model becomes

$$N_{t+1}\left[1-d-H+\frac{b+h}{td+aN_t}\right]N_t \text{(Figure 1-Eq. 3).}$$

Every scenario examined per-capita recruitment and total recruitment of population. In biological parameters also provided to enrich the discussion, such as biological impact of fishing and possible management measures. Moreover, Stability analysis conducted to identify stability in equilibrium. This model developed under Matlab programming environment.

RESULTS AND DISCUSSION

Results

Stock-density recruitment in the absence of fishing showed that an increase in population size likely led to a decrease of per-capita recruitment (PCR). An increase in density-dependent component (b) led to an increase of PCR, and then followed by an increase of total recruitment. In contrast, an increase in density-independent component (a) led to a decrease of PCR and total recruitment (Figure 2a and 2b). Moreover, an increase in 'a' as parameter of density-dependent lead to an increase in the steepness of slope (how quick the PCR decline).

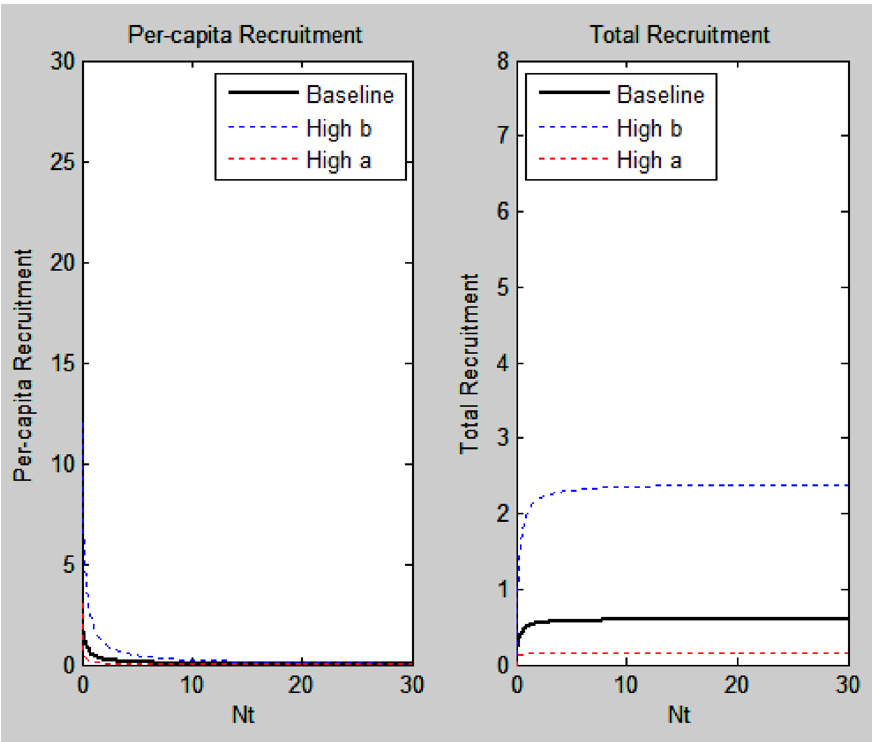

Figure 2. Per-capita recruitment (a) and total recruitment (b) of Bali sardine in the absence of fishing.

The Population dynamic on the absence of fishing has two equilibriums. First equilibrium (Eq1) is located when Nt=Nt+1=0; since the gradient is positive and the magnitude is bigger than 1, therefore small disturbance will push away population from equilibrium. Second equilibrium (Eq2) is located when population dynamic intersected line Nt=Nt+1. In this point, the equilibrium is stable, since the gradient is positive but the magnitude is less than 1. Therefore, small disturbance on equilibrium will push back population to equilibrium point. In the presence of fishing on adult population have no effect on recruitment process, since adult harvest is density independence. The equation slope is followed.

$$(Slope = 1 - d + H - \frac{baNt - b(1 + aN_t)}{(1 + aN_t)^2})$$

Eq 1 has a slope that follows 1-d-H+b; by checking inequality value to be stable |slope|<1; it is true when b-d< H < 2+b-d. Since growth rate (b-d) is less than H, so there is no population able to harvest. In contrast, in the Eq 2 the condition is hard to prove since the equation is to complex and lack of biological sense. Eq 2 is associated with carrying capacity (K) that

$$-\frac{-d^2 - 2dH + db - H^2 + hb - b}{b}$$

define as , in another word in the presence of fishing it will modified carrying capacity in which system able to maintain in the stable state. It is clearly, an increase H led to a decline in carrying capacity in which population is lower.

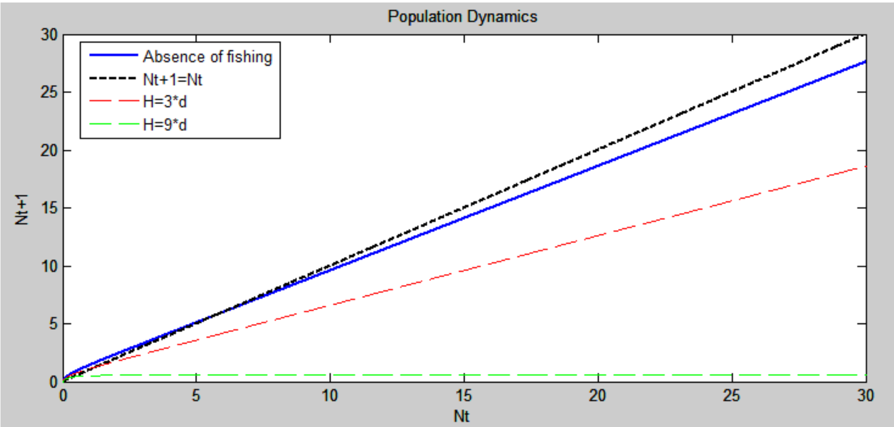

Figure 3. Population dynamic of Bali sardine in the absence of fishing (solid blue line) and presence of adult harvested in different level (dashed red and green line).

Furthermore, presence of fishing on juvenile population led to alter on recruitment process (J(t)). Stock-recruitment relationship showed that by adding fishing mortality to juvenile population (h), it would increase PCR recruitment. It could be argued by removing juvenile (an increase in h), it will decrease settlement competition mortality rate (a). Generally, an increase in density-independent component (band h) led to an increase in PCR and total recruitment (Figure 4a and 4b). In contrast, an increase in density-dependent component (a) led to a decrease in PCR and total recruitment and led to an increase in the steepness of slope (how quick the PCR decline).

Population dynamic on the presence of fishing has two equilibriums. Similarly with absence of fishing first equilibrium (Eq1) and second equilibrium (Eq2) are unstable and stable respectively. In the presence of fishing on adult and juvenile population have affect on recruitment process. The equation slope is followed .

$$(Slope = 1 - d - H - \frac{(b+h)aNt - (b+h)(1 + aN_t)}{(1 + aN_t)^2})$$

Eq 1 has a slope that follows 1-d-H+(h+b)/Td; by checking inequality value to be stable |slope|<1; it is true when. $b - d < H < 2 - d - \frac{(h+b)}{Td}$. Since density-dependent component (a) is pushed by b and h. Moreover, introduction density-independent component due to harvest in the recruitment process will increase carrying capacity (K) that refer to second equilibrium .

$$(-\frac{-d^2Td - 2dHTd + dh + db - H^2Td + Hh + Hb - h - b}{h+b})$$

Therefore, by assuming inter-specific mortality as density dependent mortality, fishing mortality in the juvenile population has positive effect on carrying capacity.

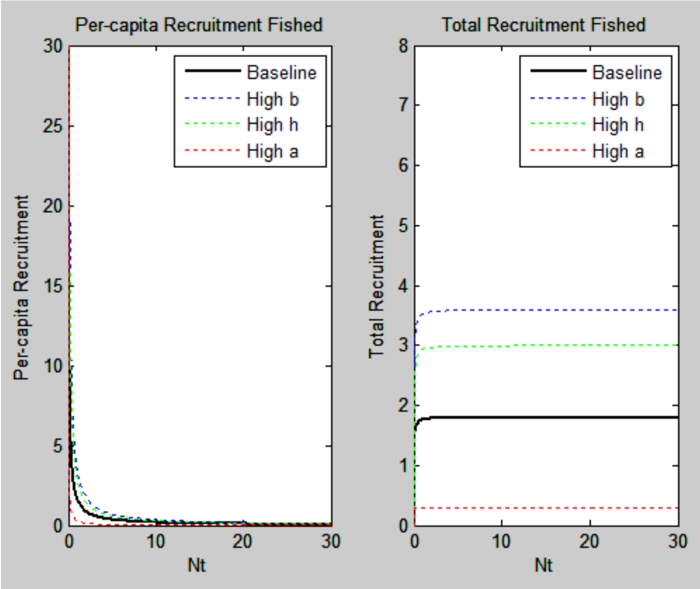

Figure 4. Per-capita recruitment (a) and total recruitment (b) of Bali sardine in the absence of fishing on juvenile population.

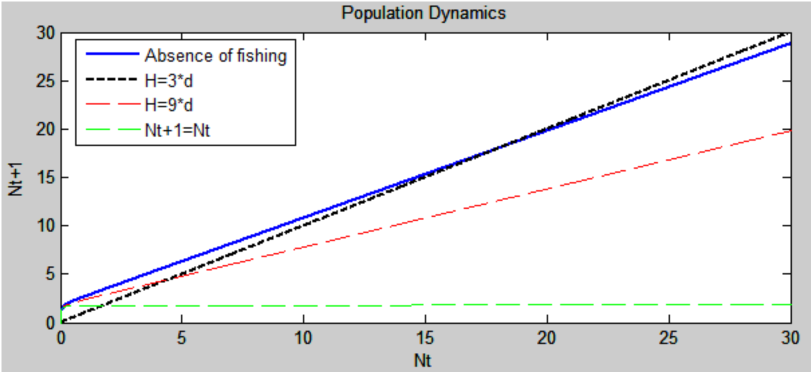

Figure 5. Population dynamic of Bali sardine in the absence of adult fishing but presence for juvenile fishing (solid blue line) and presence of adult and juvenile harvested in different level (dashed red and green line).

Discussion

Stock-recruitment relationship is the major crucial in fisheries science, however it is highly uncertainty (Hilborn & Walters, 1992). Stock-recruitment relationship is referred to the relationship between parental stock size and subsequent recruitment (Sparre & Venema, 1998). Recruitment over-fishing likely occurred when fishing pressure push the population through the limit which able to re-supply juvenile into system.

Beverton-Holt model was developed to address that issue by assuming inter-specific competition among juvenile (Beverton & Holt, 1957). Therefore, competition mortality rate is density-dependent function in respect of juvenile density. The critical assumption that fish species is extremely fecund that lead to conclusion than even a very small parental stock should be able to rebuild the stock after each spawning season. However, stock-recruitment relationship is reveal from nature (Beverton & Holt, 1957) by considering many fisheries collapsed in recent decades as an affect of recruitment over-fishing. Successful recruitment is also driven by oceanographic conditions, which are difficult to determine as stochastic. However, since most teleost fish is bipartite life cycle which characterized by (1) very high fecundity, (2) external fertilization, (3) adult benthic stage relatively sedentary, (4) eggs and larvae existing in the planktonic environment, (5) very high and unpredictable mortality rates of eggs and larvae in the plankton, and (6) potential for large-scale dispersal of eggs and larvae (Eckman, 1996).

The model showed that an increase in density-independent component led to an increase in recruitment supply. In contrast, an increase in density-dependent (inter-specific competition) will lead to recruitment decline. Since juvenile is independent to cannibalism, therefore an increase population size of adult will have positive effect (compensation) of recruitment without overcompensation effect (crowd effect of adult).

Moreover, model showed in the presence of adult harvest led to dramatically decline on recruitment supply and shifted stable equilibrium (carrying capacity) into low level. It occurred since fishing removing parental as potential spawning biomass. In contrary, an increase fishing pressure on juvenile population allowed positive grow of population. It could be argued that an increase of juvenile harvest in certain level will reduce competition among juvenile, which is have big affect on juvenile population. However, precautionary approach should be taken by considering bipartite life cycle of fish. Further study, should be conducted to investigate population that characterized by cannibalism and inter-specific competition in other word combining Ricker and Beverton-Holt model.

CONCLUSION

Precautionary approach required in managing stock of Bali Sardine since the finding indicates a bipartite life cycle. An inter-specific competition incorporated into Beverton-Holt model to examine the effect of fishing pressure that is density-independent to population dynamic by developing scenario fishing on adult and/or juvenile population. The models shown that harvested adult led to the dramatic decline of recruitment supply, while harvested juvenile led to the positive response to population size as an increase in fishing mortality rate will reduce competition mortality rate.

ACKOWLEDGMENTS

We would like to thank the support of Department of Foreign Affairs and Trade (DFAT), Australia to provide funding through Australian Awards Scholarship. Also, we thank to Prof. Dr. Sean Connolly for his constructive review and comment.

REFERENCES

Beverton, R. J. H., & Holt, S. J. (1957). *On the Dynamics of Exploited Fish Populations* (Vol. 19). London: HMSO.

Buchary, E. A. (2010). *In search of viable policy options for responsible use of sardine resources in the Bali Strait, Indonesia.* (Doctor of Philosophy - PhD), Univeristy of British Columbia.

Chow, Y., & Hsieh, J. (2013). On multidimensional discrete-time Beverton–Holt competition models. *Journal of Difference Equations and Applications, 19*(3). doi:http://dx.doi.org/10.1080/10236198.2012.656618

Eckman, J. E. (1996). Closing the larval loop: linking larval ecology to the population dynamics of marine benthic invertebrates. *Journal of experimental marine biology and ecology, 200*(1–2), 207-237. doi:http://dx.doi.org/10.1016/S0022-0981(96)02644-5

Hilborn, R., & Walters, C. J. (1992). *Quantitative fisheries stock assessment: choice, dynamics and uncertainty*. New York: Chapman and Hall.

Merta, I. G. S. (1992). *Population dynamic of Bali sardine, Sardinella lemuru Bleeker 1983 (Pisces: Clupeidae) in Bali Strait and its alternative management.* (Doctoral), Bogor Agricultural University, Bogor.

Prasetyo, A. P., & Natsir, M. (2010). *The impact extreme climate variability on the lemuru fisheries in Bali Strait.* Paper presented at the The Best Research, Bandung.

Puspasari, R., Rahmadi, P., Rahmawati, P. F., & Samu-Samu, A. S. (2015). Climate variability interaction with coral reef ecosystem and reef fish resources. *J. Lit. Perikan. Ind, 21*(4), 211-220.

Setyohadi, D. (2010). *Study of lemuru resources utilization (Sardinella lemuru) in Bali Strait: simulation analysis of management policies 2008-2020.* (Doctoral), Brawijiya University, Malang.

Sparre, P., & Venema, S. C. (1998). *Introduction to tropical fish stock assessment. Part 1. Manual*. Rome: FAO.

Wudianto, & Wujdi, A. (2014). Size variation of Bali Sardinella (*Sardinella lemuru* Bleeker, 1953) based on temporal and spatial in Bali Strait Waters. *J. Lit. Perikan. Ind, 20*(1), 9-17.

Wujdi, A., Suwarso, & Wudianto. (2012). Some population parameters of Bali sardinella (*Sardinella lemuru* bleeker, 1853) in Bali Strait waters. *Bawal, 4(3)*, 177-184.