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BEBERAPA CATATAN TENTANG ASOSIASI ANTARA IKAN SUKU CARAPIDAE DAN EKHINODERMATA

oleh

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ABSTRACT

SOME NOTES ON ASSOCIATION BETWEEN PEARLFISHES (CARAPIPADE) WITH ECHINODERMS. *It is well known that some pearlfishes dwell within the bodies of echinoderms and other invertebrates. Some habits of this fishes already studied by ARNOLD (1953, 1957), and by some other authors. About nine species of the pearlfishes are widely distributed in the region Indo-West Pacific, about four among them are reported from Indonesian waters. All of known species of the pearlfishes can be found on coral reef areas. The holothurians are known as more common hosts, especially* **Stichopus chloronotus**. *Their seasonal variations are supposed to be related with their life history.*

PENDAHULUAN

Asosiasi antara ikan suku Carapidae dengan kelompok ekhinodermata tertentu telah lama menarik perhatian para ahli. Menurut JANGOUX (1974), asosiasi ini pertama kali dilaporkan oleh dua orang pakar bangsa Perancis QUOY dan GAIMARD yang meneliti biosistematik kelompok teripang yang berasal dari pelayaran ilmiah ASTROLABE di Atlantik yang berlangsung antara tahun 1826 sampai 1829. Selain dengan kelompok ekhinodermata, ikan suku Carapidae ini juga dilaporkan berasosiasi dengan invertebrata lainnya. Tetapi frekuensi kehadiran ikan ini lebih kerap pada kelompok ekhinodermata, terutama pada jenis-jenis teripang.

Kehadiran ikan suku Carapidae ini di perairan. Indonesia, pertama kali dilaporkan oleh BLEEKER pada tahun 1854 dan oleh DOLESCHALL pada tahun 1858, masing-masing dari perairan sekitar Ternate dan Ambon (JANGOUX 1974). WEBER (1913), juga melaporkan kehadiran ikan suku Carapidae ini yang diperoleh dari perairan Maluku oleh ekspedisi SIBOGA. Ikan suku Carapidae ini juga telah banyak dilaporkan dari kawasan Indo Pasific Barat lainnya. Antara lain dilaporkan oleh PETIT dalam JANGOUX (1974) dari perairan sekitar India; oleh HERRE & HERALD (1950), TROTT & GARTH (1970), TROTT & TROTT (1973) dari perairan Filipina; oleh CHENEY (1973) dari perairan sekitar Guam; oleh BONHAM (1960) dari kepulauan Marshall; dan oleh STRASBURG (1961) dari perairan Hawaii dan sekitarnya. Ikan suku Carapidae ini juga telah dilaporkan kehadirannya dari lautan Atlantik, antara lain oleh ARNOLD (1953, 1957), dan oleh DAWSON (1971).

SISTEMATIKA IKAN SUKU CARAPIDAE

Ikan suku Carapidae dikenal dengan nama umum sebagai ikan mutiara atau pearlfish. Ikan ini berukuran relatif kecil antara 100 mm sampai 200 mm, dengan bentuk

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umum mirip miniatur ikan layur dengan tubuh lebih silindris, ekor lancip dan kepala agak termampat dorsolateral. Ikan ini termasuk dalam bangsa (ordo) GADIFORMES, suku atau famili CARAPIDAE. Kedudukan di tingkat marga (genera) dari ikan ini belum sepenuhnya terpecahkan. Beberapa revisi mengenai ikan ini telah dilakukan antara lain oleh ARNOLD (1956) dan TYLER (1970), namun beberapa marga masih diragukan validitasnya. Kurang lebih 9 jenis ikan suku Carapidae ini yang mewakili 3 marga tersebar luas di kawasan Indo Pacific. Ikan tersebut adalah: *Campus homei, C. mourlani, C parvipinnis, C. margaritiferae (Onuxodon margaritiferae), Onuxodon parvibrachium, Encheliophis parvibrachium, E. vermicularis, E. sagamianus, E. gracilis (= Jordanicus gracilis), Fierasfer sluiteri* Jenis yang terakhir ini *(Fierasfer sluiteri)* hanya terdapat dari perairan Indonesia, dilaporkan oleh WEBER (1913). Jenis ini tidak pernah lagi ditemukan oleh pakar lainnya dan agaknya kedudukan marga *Fierasfer* sudah tidak valid lagi, mengingat semua jenis yang tadinya termasuk marga ini telah dipindahkan ke dalam marga *Carapus.* Jenis-jenis lainnya yang terdapat di perairan Indonesia adalah *Carapus homei, Encheliophis gracilis,* dan *Carapus parvipinnis.* Agaknya revisi menyeluruh bagi ikan suku Carapidae ini masih diperlukan.

HABITAT dan PENYEBARAN IKAN SUKU CARAPIDAE

Mengingat inang atau host dari ikan suku Carapidae adalah terutama dari kelompok ekhinodermata, seperti jenis-jenis teripang dan bintang laut tertentu, yang hidup pada komunitas terumbu karang yang tersebar antara kedalaman 0 m sampai 45 m. Diduga penyebaran ikan ini pun mengikuti pola penyebaran binatang karang. Jenis teripang yang paling populer sebagai inang adalah *Stichopus chloronotus* untuk kawasan Indo Pacific Barat dan *Holothuria tubulosa* untuk daerah Laut Tengah. Jenis bintang laut yang disukai sebagai inang adalah bintang laut berukuran besar seperti marga *Culcita* dan *Choriaster.* Menurut penelitian para pakar seperti ARNOLD (1953) dan SMITH (1964), kehadiran ikan suku Carapidae ini pada inangnya terutama untuk kelompok teripang ternyata cukup besar, yaitu berkisar antara 10% sampai 90% dari jumlah teripang yang diteliti. Sejenis teripang, yaitu teripang keling atau *Holothuria atra* merupakan jenis teripang yang dihindari atau tidak disukai oleh ikan suku Carapidae ini. Menurut SMITH (1964), dari 107 ekor teripang jenis *Holothuria atra* yang ditelitinya, ternyata tak seekorpun yang membawa ikan ini, padahal di tempat dan saat yang sama teripang jenis *Stichopus chloronotus* memperlihatkan sekitar 80% kehadiran ikan ini. Pakar tersebut menambahkan, bahwa kemungkinan tidak disukainya jenis *Holothuria atra* oleh ikan suku Carapidae ini mungkin disebabkan oleh tidak adanya kelenjar getah pada jenis teripang tersebut. Berdasarkan telusur pustaka ternyata bahwa kehadiran ikan suku Carapidae ini pada kelompok teripang tidaklah dipengaruhi oleh adanya kelenjar getah pada teripang tersebut. Lebih lanjut BONHAM (1960) dan STRASBURG (1961), juga melaporkan bahwa teripang jenis *Holothuria atra,* juga merupakan inang atau host yang tidak disukai oleh ikan suku Carapidae tersebut. Alasan yang tepat mengapa jenis teripang ini dihindari belumlah diketahui. Menurut YAMANOUCHI dalam BAKUS (1973), kehadiran ikan suku Carapidae ini pada kelompok teripang juga tidak berkaitan dengan terdapatnya kandungan racun holothurin pada teripang, tetapi kehadiran ikan tersebut lebih dipengaruhi oleh ukuran diameter dari cloaca teripang bersangkutan. Selain teripang jenis *Stichopus chloronotus,* teripang lainnya yang pernah dilaporkan sebagai inang dari ikan Carapidae ini adalah: *Stichopus variegatus, Bohadschia argus* dan *Thelonota ananas.*

Kelompok Asteroidea atau bintang laut yang disukai terutama yang mempunyai ukuran besar seperti *Culcita novaeguineae, Choriaster granulosus,* dan *Culcita schmideliana* juga dilaporkan sebagai inang dari ikan suku Carapidae ini. Informasi lebih lanjut tentang asosiasi antara ikan suku Carapidae dan kelompok Asteroidea telah diberikan oleh JANGOUX (1974). Selain kelompok ekhinodermata, jenis-jenis Moluska tertentu juga pernah dilaporkan sebagai inang dari ikan suku Carapidae ini, seperti oyster jenis *Pycnodonta hyotis* dan kerang mutiara jenis *Pinctada maxima.* Jenis ikan, biota inang (host) dan penyebarannya dapat dilihat pada Tabel 1 dan 2.

Tabel 1. Jenis ikan Carapidae, hewan inang, dan penyebarannya di kawasan Indo Pasifik Barat.

Jenis inang	Jenis ikan	Lokasi	Pakar
ASTEROIDEA			
Acanthaster planci	*Encheliophis gracilis*	Guam	4
Choriaster granulosus	*Carapus homei*	Seychelles	5
Culcita disocidea	*Carapus homei*	Ceram, Ternate	1
	Encheliophis gracilis	Ambon	1
Culcita novaeguineae	*Carapus mourlani*	Madagascar, Guam, Luzon	1, 12
	Fierasfer sp.	Ambon	2
Culcita schmideliana	*Carapus homei*	Madagascar,	1, 5
	Fierasfer sp.	Mauritius	3
Certonardoa semiregularis	*Encheliophis sagamianus*	Jepang	1
Mithrodia fisheri	*Carapus homei*	Seychelles	5
HOLOTHUROIDEA			
Bohadschia argus	*Carapus homei*	Luzon, Ceram	8 9 12
Bohadschia marmorata	*Encheliophis gracilis*	*Guam*	12
Holothuria atra	*Encheliophis gracilis*	Hawaii	7
Stichopus chloronotus	*Carapus homei*	Borneo, Luzon, Guam, Marshall	6, 8 10, 12
Stichopus variegatus	*Carapus homei*	Saleyer	10
Stichopus vastus	*Carapus parvipinnis*	Sulawesi	10
Thelonota ananas	*Carapus parvipinnis*	Guam	12
TUNICATA			
Styela aurata	*Fierasfer sluiteri*	Rotti, Timor	10
MOLLUSCA			
Pycnodonta hyotis	*Onuxodon parvibrachium*	Seychelles,	11
		Luzon	8
	Onuxodon margaritiferae	Luzon	8
Pinctada maxima	*Carapus homei*	Jepang	1

1. Ditabulasikan oleh JANGOUX, 1974	7. STRASBURG, 1961
2. MORTENSEN, 1923	8. TROTT & TROTT, 1972
3. MORTENSEN, 1931	9. TROTT & GARTH, 1970
4. CHENEY, 1973	10. WEBER, 1913
5. JANGOUX, 1974	11. TYLER, 1970
6. BONHAM, 1960	12. SMITH, 1964

Tabel 2. Jenis ikan Carapidae, hewan inang, dan penyebarannya di Atlantik.

Jenis inang	Jenis ikan	Lokasi	Pakar
HOLOTHUROIDEA			
Actinopyga agassizi	*Carapus bermudensis*	Tel. Mexico	2
Holothuria mexicana	*Carapus bermudensis*	Tel. Mexico	2
Holothuria tubulosa	*Carapus acus*	Tel.Napel	1
Isostichopus badionotus	*Carapus bermudensis*	Bahama	2
Stichopus regalis	*Carapus acus*	Tel.Napel	1
Theelothuria princeps	*Carapus bermudensis*	Mexico	2

1. ARNOLD, 1953
2. PAWSON, 1971

SIFAT ASOSIASI

Ikan suku Carapidae stadium muda diduga sebagai parasit sejati yang senantiasa berdiam dalam rongga tubuh inangnya, dan ikan stadium juvenile dan ikan dewasa bersifat endokomensal dan tidak lagi terlalu tergantung pada inangnya. Sifat asosiasi ini telah diteliti oleh ARNOLD (1953, 1957) dan oleh SMITH (1964). Menurut ARNOLD (1953), sifat asosiasi ikan suku Carapidae ini ada kaitannya dengan stadium pertumbuhan dari ikan tersebut. Penelitian ARNOLD tersebut didasarkan atas penelitian PADOA (1947), yang meneliti ikan jenis *Carapus acus* yang hidup di Laut Tengah. ARNOLD (1953), membagi tahapan kehidupan ikan ini dalam 4 stadium pertumbuhan.

Stadium pertama, adalah ikan yang baru menetas yang disebut sebagai larva vexillifer. Larva ini ditandai oleh vexillum dorsal yang relatif memanjang. Larva vexillifer ini hidup bebas sebagai plankton. Vexillifer stadium lanjut dapat mencapai panjang total sekitar 60 mm.

Stadium kedua disebut sebagai tenuis, berupa ikan stadium muda yang hidup sebagai parasit di dalam rongga tubuh (coelom cavity) dari hewan inang. Pada stadium tenuis ini ikan dapat mencapai panjang total antara 80 mm sampai 135 mm.

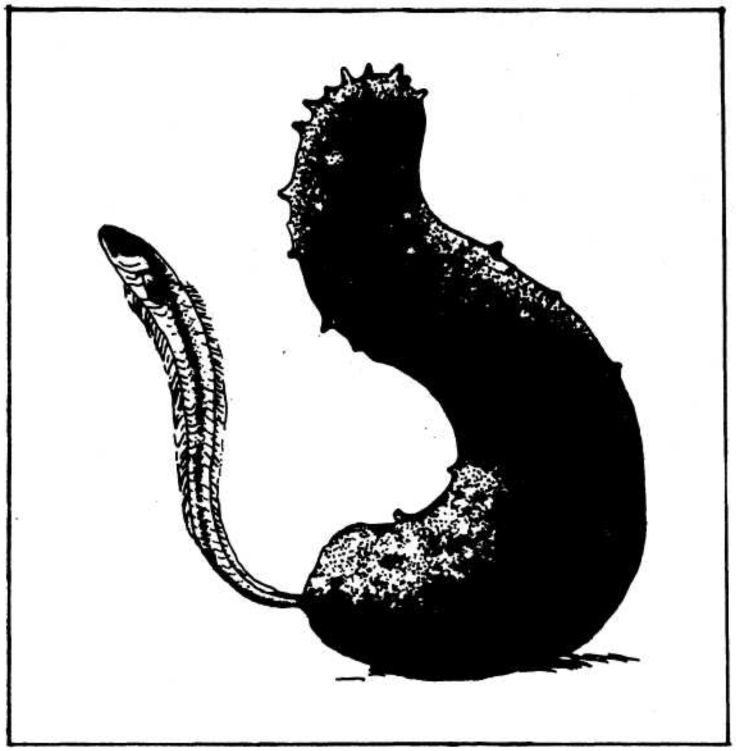
Stadium ketiga disebut sebagai juvenil, di mana ikan tersebut mengalami beberapa perubahan morfologi dan mengalami pemendekan dari panjang totalnya. Untuk jenis *Carapus acus* ini berkisar antara 59 mm sampai 90 mm. Ikan stadium juvenile ini berpindah dari rongga tubuh ke daerah cloaca dan hidup sebagai endokomensal pada inangnya.

Stadium keempat adalah stadium dewasa. Ikan jenis *Carapus homei* ini pada stadium dewasa dapat mencapai panjang total antara 100 sampai 190 mm. Ikan stadium dewasa ini sewaktu-waktu dapat meninggalkan tubuh inangnya untuk mencari makan. Tetapi ikan tersebut bisa masuk kembali ke tubuh inangnya untuk berlindung. Menurut pengamatan para pakar di atas ikan dewasa ini aktif mencari makan di malam hari, dan pada siang hari tetap berdiam di dalam cloaca dari inangnya. Berdasarkan analisis isi lambung diketahui bahwa ikan stadium tenuis yang berada dalam rongga tubuh inangnya, hidup dengan makan potongan gonad ataupun bagian visceral lainnya dari hewan inang. Hal tersebut telah dilaporkan oleh banyak pakar, antara lain oleh STRASBURG (1961), SMITH (1964), TROTT (1970), TROTT & TROTT (1972), dan JANGOUX (1974). Selanjutnya para pakar tersebut melaporkan bahwa kehadiran ikan suku Carapidae ini tidaklah terlalu merugikan hewan inangnya, hewan inang yang ditumpanginya tetap hidup normal dan menjalankan fungsinya dengan baik.

ARNOLD (1957), lebih lanjut melaporkan bahwa ada dua hal yang menyebabkan larva vexillifer tertarik kepada inangnya, terutama untuk kelompok teripang. Pertama adanya arus lokal pada anus teripang yang timbul akibat proses pernafasan pada teripang tersebut, seirama dengan membuka dan menutupnya anus. Kedua adanya substansi kimia yang terkandung dalam mukus di daerah cloaca dan anus, zat kimia ini rupanya menjadi daya tarik untuk larva vexillifer dari ikan suku Carapidae. JANGOUX (1974), mengemukakan bahwa pada kelompok bintang laut, ikan ini tidak mungkin keluar masuk melalui anusnya, mengingat anus bintang laut relatif lebih sempit dan tidak fleksibel. Pakar tersebut menduga ikan memasuki tubuh bintang laut lewat mulutnya, tetapi hal ini belum sepenuhnya dimengerti mengingat mulut bintang laut selalu dengan posisi menghadap ke dasar. Pada setiap inang biasanya tidak lebih dari seekor ikan Carapidae, sangat jarang dua atau lebih. Untuk jenis *Carapus homei* yang hidup tersebar luas di kawasan Indo Pacific Barat, hal ini dapat diterangkan oleh adanya sifat kanibal pada ikan tersebut. Berdasarkan analisis isi lambung dari ikan stadium tenuis dari ikan *Carapus homei* yang hidup di rongga tubuh inangnya ternyata terdapat sisa potongan ikan dari jenis yang sama. Sifat kanibal di sini rupanya diperlukan untuk mempertahankan hanya ada satu ikan untuk setiap inang. Tetapi TROTT & GARTH (1970), melaporkan dari perairan Filipina, bahwa ikan *Carapus homei* ini dapat hidup bersama dengan sejenis kepiting *Lissocarsinus orbicularis* yang ditemukan hidup damai dalam rongga tubuh inang yang sama. Kedua pakar tersebut juga melaporkan bahwa ikan jenis *Jordanicus gracilis* tidak pernah ditemukan bersamaan dengan kepiting *Lissocarsinus orbicularis.* Karena ikan jenis *Jordanicus gracilis* mempunyai ukuran tubuh yang relatif lebih besar dari *Carapus homei,* maka diduga kepiting ini kalah bersaing dalam memperebutkan tempat dalam ronga tubuh inang.

Ikan suku Carapidae ini cukup selektif dalam menentukan hewan inangnya. ARNOLD (1953) melaporkan bahwa ikan *Carapus acus* kerap kali ditemukan dalam tubuh teripang *Holothuria tubulosa* (Gambar 1), jarang pada *Stichopus regalis,* dan tidak pernah pada *Holothuria poli, H. forskali, H. helleri* Sedangkan ikan jenis *Carapus homei* ternyata mempunyai sekitar 8 jenis inang yang berbeda (Tabel 1). Ikan jenis *Onuxodon parvibrachium* dan *Onuxodon margaritiferae* selalu memilih inang dari kelompok Moluska.

SMITH (1964), mengemukakan sangat sulit untuk mengidentifikasikan jenis-jenis ikan Carapidae ini, karena mereka mempunyai 4 stadium yang berbeda dalam hidupnya. Sehingga ikan dengan ukuran yang sama dapat berstatus tenuis lanjut, juvenile ataupun dewasa. Hanya perbedaan sifat terinci dari setiap stadium tersebut yang dapat membantu memecahkan problema identifikasi ini. Beberapa catatan dari ikan *Carapus acus* yang diteliti oleh ARNOLD (1953), mungkin bisa dipakai untuk membantu pembedaan bentuk tenuis dan dewasa. Ikan stadium tenuis dan dewasa dengan panjang total yang sama ternyata mempunyai ciri terinci yang berbeda, misalnya panjang kepala yang relatif lebih pendek pada ikan.



Gambar 1. Aktifitas ikan *Carapus* dewasa sekitar anus dari teripang *Holothuria tubulosa* (modifikasi dari ARNOLD 1953).

dewasa. Ikan dengan ukuran panjang kepala 12 mm sampai 17 mm (tenuis) akan tereduksi sehingga hanya berukuran 7 mm sampai 9 mm saja pada stadium dewasanya. Posisi anus terhadap sirip dada (pectoral fin) pun ternyata memperlihatkan perbedaan juga. Anus pada ikan stadium tenuis terletak pada posisi posterior dari sirip dada, sedangkan pada stadium dewasa anus terletak pada posisi anterior dari sirip dada.

Sifat asosiasi antara ikan suku Carapidae ini dan hewan inangnya belum sepenuhnya terungkapkan, namun para pakar menduga sifat asosiasi ini tidak jauh berbeda dari ikan *Carapus acus,* seperti yang dilaporkan oleh ARNOLD (1953, 1957).

KERAGAMAN MUSIMAN

Menurut SMITH (1964), yang meneliti asosiasi ikan suku Carapidae ini di perairan Guam dan sekitarnya, terdapat semacam fluktuasi musiman dari kehadiran ikan ini pada inangnya. Untuk hal ini khusus diteliti teripang jenis *Stichopus chloronotus* yang dikenal sebagai inang yang paling umum. Frekuensi kehadiran ikan cukup tinggi, yaitu berkisar antara 71% sampai 88% pada bulan Nopember sampai Maret, dan relatif berkurang sampai sekitar 16% - 31% pada bulan Mei dan Juni. Menurut pakar tersebut perbedaan persentase kehadiran ini tidaldah dipengaruhi oleh kelimpahan hewan inang, tetapi diduga ada kaitannya dengan daur hidup ikan tersebut. Penelitian yang lebih khusus masih diperlukan untuk mempertajam dugaan tersebut. Kehadiran ikan suku Carapidae ini juga bervariasi terhadap tempat, terlihat adanya perbedaan persentase kehadiran pada tempat pengamatan yang berbeda. Khusus untuk perairan Indonesia, penelitian asosiasi antara ikan Carapidae dan ekhinodermata ini secara khusus belum pernah diadakan. Semoga tulisan ini cukup memberikan informasi seperlunya dan mendorong rekan-rekan peneliti untuk mengamatinya.

DAFTAR PUSTAKA

ARNOLD, D.C. 1953. Observations on *Corapus acus* (Brunnich), (Jugulares, Carapidae). *Publ. Sta. zool. Napoli,* 24 : 152 - 166.

ARNOLD, D.C. 1957. Further studies on the behaviour of the fish *Carapus acus* (Brunnich). *Publ sta. zool. Napoli* 30 (2) : 263 - 268.

BAKUS, G.J. 1973. The biology and ecology of tropical holothurians. *In* : O.A. JONES & R. ENDEAN (eds.) : 325 - 467. New York, Academic Press.

BONHAM, K. 1960. *Carapus homei* (Richardson) in a sea cucumber from the Marshall Islands. *Copeia* 1960 (3) : 255 - 257.

CHENEY, D.P. 1973. Pearlfish (Carapidae) in *Acanthaster planci* (L). *Micronesica 9* : 159 - 169.

DAWSON, C. E. 1971. Records of the Pearlfish, *Carapus bermudensis* in the Nothern Gulf of Mexico and of a new host species. *Copeia* 1971 (4): 730-731.

HERRE, A.W. and E.S. HERALD 1950. Noteworthy additions to the Philippine fish fauna with descriptions of a new genus and species. *Philipp. J. scien.* 79 (3) : 309 - 340.

JANGOUX, M. 1974. Sur l'association entre cartaines Asteries (Echinodermata) et des poissons Carapidae. *Rev. zool. afr.* 88 (4) : 789 - 796.

MORTENSEN, T. 1923. The Danish expedition to the Kei Islands 1922. *Videnks. Medd. dansk Naturh. Foren. KOB.* 76 : 25 - 99.

MORTENSEN, T. 1931. Contributions to the study of the development and larval forms of Echinoderms I - II. *Kong. dansk. vidensk selsk. skrift. Naturvid. Math. Afd.* (9)4:3-39.

SMITH, C.L. 1964. Some pearlfishes from Guam, with notes on their ecology. *Pacific sci.* 18(1): 34-40.

STRASBURG, D.W. 1961. Larval carapid fishes from Hawaii, with remarks on the ecology of adults. *Copeia* 1961 (4) : 478 -480.

TROTT, L.B. and J.S. GARTH 1970. *Lissocarcinus orbicularis* Dana (Portunidae, Caphyrinae), commensal with *Holothuria argus* Jaeger, A new host record; cohabitation with the pearlfish, *Carapus homei* (Richardson). *Crustaceana* 19 (3) : 320-321,

TROTT, L.B. and T.E. TROTT 1973. Pearlfishes (Carapidae; Gadiformes) collected from Puerto Galera, Mindoro, Philippines. *Copeia* 1972 (4) : 839 - 843.

TYLER, J.C. 1970. A redescription of the inquiline Carapid fish Onuxodon parvibrachium, with a discussion of the skull structure and the host. *Bull. mar. sci.* 20 (1): 148-164.

WEBER, M. 1913. Die Fische der Siboga - Expedition. *Siboga Exped.* 57 : 95 - 97.

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SURPLUS PRODUCTION MODELS AND ANALYSIS OF EXPLOITED POPULATION IN FISHERIES

by

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ABSTRAK

MODEL 'SURPLUS PRODUCTION' DAN ANALISIS TERHADAP POPULASI DI BIDANG PERIKANAN. *Didalam ilmu dinamika populasi perikanan, kelompok model ini dapat digolongkan ke dalam model yang paling sederhana, dalam arti mudah dimengerti (meski oleh kaum awam sekdipun), tidak memerlukan banyak macam data, serta didasari oleh pengertian matematika yang mudah. Konsep-konsep yang melandasi model ini dibahas secara rinci, termasuk pula beberapa kelemahan dan keunggulannya bila diterapkan untuk melakukan analisis terhadap dinamika dari suatu populasi di bidang perikanan, Selain itu dikemukakan pula beberapa contoh penggunaan model tersebut, antara lain untuk perikanan lemuru di Selat Bali.*

INTRODUCTION

Fisheries represent dynamic (time varying) system with interacting components, such as biology, technology, economy, politic, and social. Mathematical models in fisheries try to capture how a system works by expressing the interactions in terms of mathematical relationships.

The simplest model in fisheries population dynamics is the surplus yield, surplus production, Schaefer models, or logistic production models. Actually, this simple yield approach can be traced back to GRAHAM (1935), so that some authors prefer to name it as Graham-Schaefer model. These models consider a fish population as a single entity, subject to simple rules of simple population growth. Increasing or decreasing process in biomass subsumes a number of real population processes such as tissue growth and recruitment as input parameters and mortality as output parameter.

Consequently, analysis of fish population based upon these models can be made when only very little information, primarily on the catch, the population biomass, and the amount of fishing which usually expressed as fishing effort, are available. These models ignoring the events within a population and the growth and mortality of the individuals forming the population.

POPULATION GROWTH FORM

Before discussing the growth of a population, it is necessary to define the word population. In this paper, population defined as all collection group of fish of the same species inhabiting a particular space which enable them to interbreed independently. Each of population has its characteristic patterns of increase which called as population growth form. Two population growth forms, i.e. exponential growth and sigmoid growth forms, are important in the study of fish population dynamics.

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1. Exponential Population Growth Form

Exponential growth form known also as J-shaped, geometric, or Malthusian population growth. This last name is derived fron that of THOMAS ROBERT MALTHUS (1766-1834) who pointed out that all species had, theoritically, an ability to increase that finally would exceed any conceivable increase in the means of subsistance of those species (PIELOU 1974).

Unchecked exponential growth of a population, i.e. the environment is unlimited in space, food, and other organisms not exerting a limiting effect, will lead to a *population explosion.*

Let us suppose that in general, at the end of any unit of time there are always X times as many individuals as there were at the be-ginning of the unit of time, and let

$$N_0, N_1, N_2, N_3, \ldots N_t$$

denote the size of the population at time

$$t = 0, 1, 2, 3, \ldots t$$

then,

$$N_1 = \lambda N_0$$

$$N_2 = \lambda N_1 = \lambda^2 N_0$$

$$N_3 = \lambda N_2 = \lambda^2 N_1 = \lambda^2 N_0$$

.

.

.

$$N_t = \lambda^t N_0$$

Thus, the size of the population at the sequence of times is

$$\begin{array}{ccccc} 0 & 1 & 2 & 3 \quad \ldots & t \\ N_0 & \lambda N_0 & \lambda^2 N_0 & \lambda^3 N_0 & \lambda^t N_0 \end{array}$$

which demonstrate a geometric series. The constant λ is known as the finite rate of pupulation growth.

In the exponential population growth form, the population is growing exponentially or like a sum of money earning compound interest with interest compounded annualy. Then N_t, the size of the population after *t* years is

$$N_t = N_0 (1 + r)^t \ldots \qquad (1)$$

where *r* is the interest rate expressed as a fraction.

Numerical example : let N_0 = 1 000 be the sum of muney (in rupiah) saved in bank at time *t* = 0, and *r* be the interest rate = 0.1.5 per year, then at time

$$\begin{array}{lll} t=1 & N_1 & = 1\,000 + (1\,000 \times 0.15) \\ & & = 1\,000(1 + 0.15) \\ & & = N_0(1+0.15) \\ t=2 & N_2 & = N_1 + (N_1 \times 0.15) \\ & & = N_1(1+0.15) \\ & & = N_0(1+0.15)^2 \\ t=3 & N_3 & = N_2 + (N_2 \times 0.15) \\ & & = N_2(1+0.15) \\ & & = N_0(1+0.15)^3 \\ \cdot & & \\ \cdot & & \\ \cdot & & \\ t & N_t & = N_{t-1} + (N_{t-1} \times 0.15) \\ & & = N_{t-1}(1+0.15) \\ & & = N_0(1+0.15)^t \end{array}$$

Consider again the compound interest law of

$$N_t = N_0 (1+r)^t$$

If interest were compounded *n* times a year instead of annually, Eq. (1) would become

$$N_t = N_0 \left(1 + \frac{r}{n}\right)^{nt}$$

and if *n* becomes very large, it may be shown that in the limit $N_t \longrightarrow N_0 e^{rt}$ where $e = 2.71828 \ldots$ is the base of the natural (or Napierian) logarithms.

The arithmetic plots of the exponential population growth demonstrate the J-shaped growth curve as shown in Figure 1. The constant *r* is known as the instantaneous rate of

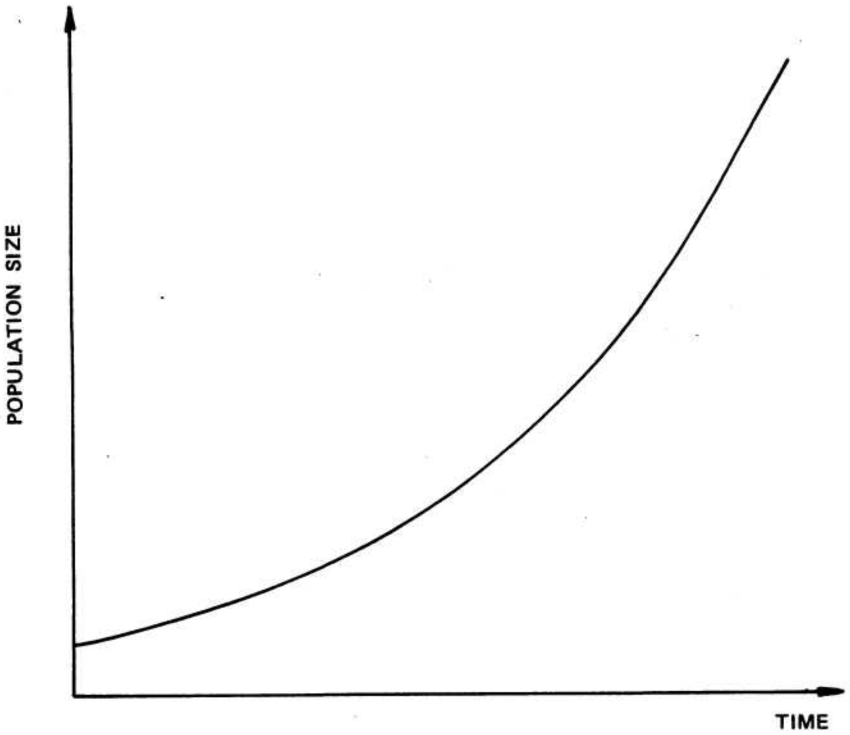

Figure 1. Exponential growth curve.

population growth. Thus the relation between λ and *r* is this : in so far as the equations

$$\frac{Nt}{N0} = \lambda^{t} \quad \text{and} \quad \frac{Nt}{N0} = e^{rt}$$

are equivalent, it follows that $\lambda = e^{r}$ or $r = \ln \lambda$, where $\ln \lambda$ denotes $\log_e \lambda$, the natural logarithm of λ. The rate of increase *r* is a composite parameter reflecting the difference between birth rate *b*, and death rate *d,* such that $r = b - d$ (these are instantaneous rates).

2. Sigmoid Population Growth Form

The abundance of a fish species is not a fixed quantity and it varies from one place and one time to another, resulting spatial and temporal patterns. Fluctuations are subject to the changing balance between death and birth rates and by the availability of resources. The other simple population growth form that we usually can study is the sigmoid curve or S-shaped form which describes the way in which the size of a pupulation approaches an asymptotic and fluctuates about it as the relationship changes between births and deaths. Mathematically, the sigmoid growth form can be expressed in a differential equation as

$$\frac{dN}{dt} = rN\left(\frac{K - N}{K}\right) \text{.....(2)}$$

where $\frac{dN}{dt}$ = the rate of population growth change (in number in time), K is the population abundance which can be supported by the environment (the carrying capacity), N is the population size, and *r* is the specific growth rate. The shape of the curve describing the growth of N, assuming the sigmoid curve is valid, is shown in the Figure 2.

Starting from a low N, abundance increase slowly at first, then faster until the rate of increase drops away as N approaches K. The carrying capacity is the population abundance towards which the population converges as equilibrium is disturbed.

The term of $(\frac{K - N}{K})$ in Eq. (2) describes detrimental factors created by the growing population itself, i.e. whenever N increases, $\frac{dN}{dt}$ decreases. In general, sigmoid curve characterized by the greater and greater detrimental factors as the abundance of the population increases. The growth to be *logistic* whenever detrimental factors are linearly proportional to the population size.

SURPLUS PRODUCTION MODELS

The basis of the production models is biomass regeneration, which considered as a single entity process, ignoring the events of recruitment, growth, and mortality of the individuals composing the population. These models assume that biomass produced over that needed for exact replacement is regarded as a *surplus* which can therefore be harvested. This first assumption can be depicted in Figure 3, where B(t) and B(t+1) are biomass at time t and t+1, B_∞ is the biomass maximum, and Y_E is the equilibrium yield.

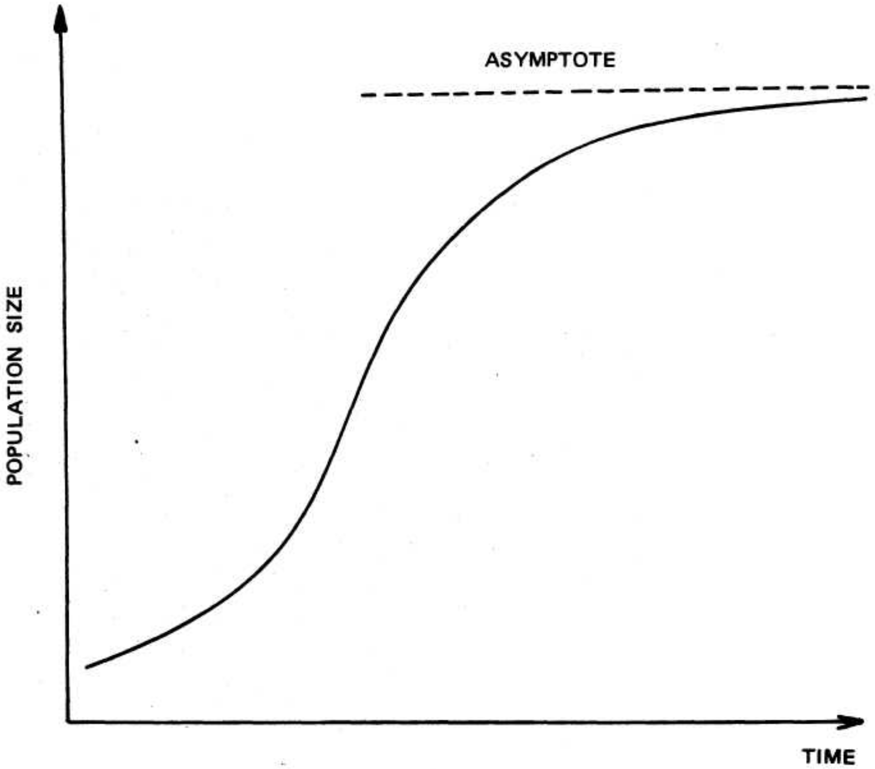

Figure 2. Sigmoid growth curve.

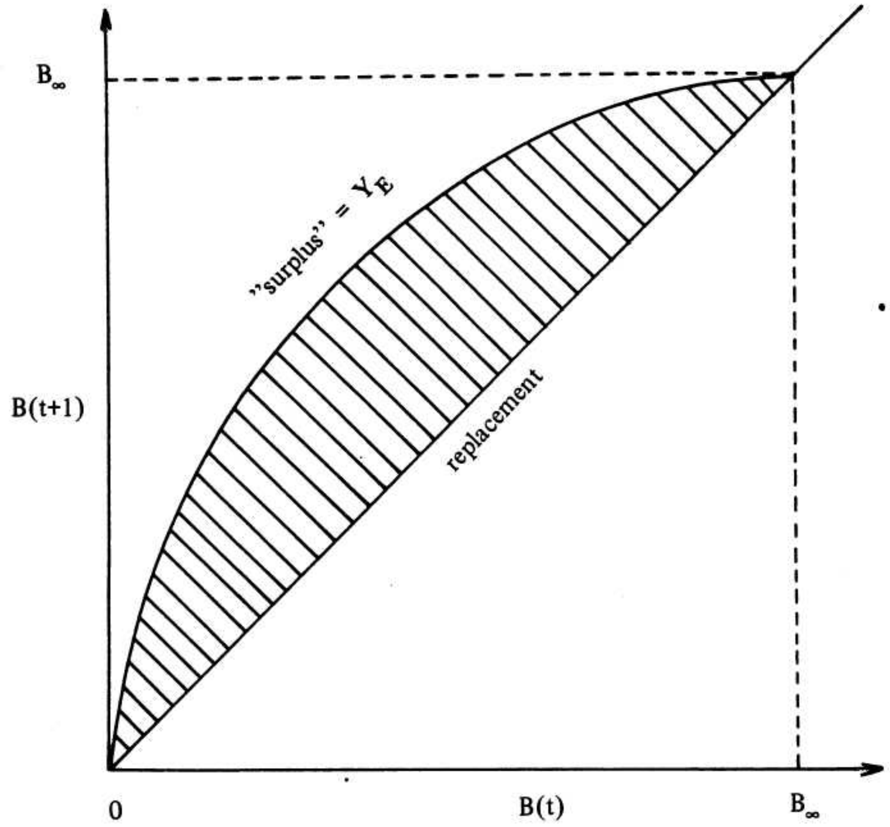

Figure 3. Biomass of time = t plotted against biomass of time = t+1 to demonstrate the basic assumption of surplus production models.

The second assumption is that when the quantity of biomass taken in the fishery is exactly equal to the surplus produced, the fishery is assumed to be in steady state (equilibrium), providing an equilibrium yield, Y_E.

1. Parabolic Surplus Production Curve — GRAHAM'S Method

GRAHAM (1935) postulated that under steady state conditions the logistic growth equation could apply to the biomass regeneration function, i.e. the rate of surplus production of stock (= recruitment + growth less natural mortality) is directly proportional to its biomass and also to the difference between the actual biomass and the maximum biomass the area will support

$$\frac{dB}{dt} = kB\left(\frac{B_\infty - B}{B_\infty}\right)........(3)$$

where $\frac{dB}{dt}$ the rate of surplus production of the stock

B stock size (biomass)

B_∞ maximum biomass that could be supported by the environment.

k the instantaneous growth rate at small biomass.

t time, conventionally in year.

Note: Integrating Eq. (3), the growth curve is the sigmoid logistic curve Verhulst (RICKER 1975)

$$B = \frac{B_\infty}{1 + e^{-k(t-t_o)}}$$

where t0 is the inflection point of the curve, i.e. $t - t_0 = 0$ when $B = \frac{B_\infty}{2}$. Therfore, surplus production models also well known as logistic production models.

Based upon the second assumption, i.e. when fishing remove the surplus production of the stock at the same rate as it is produced, it becomes the annual yield from a stock held in equilibrium, mathematically can be expressed as

$$\frac{dB}{dt} = k B_E\left(\frac{B_\infty - B_E}{B_\infty}\right) - F_E B_E = 0$$

$$Y_E = F_E B_E = k B_E\left(\frac{B_\infty - B_E}{B_\infty}\right)$$

$$Y_E = k B_E - \frac{k B_E^2}{B_\infty} \quad \ldots \quad (4)$$

where B_E biomass of stock in steady state conditions.

F_E rate of fishing which maintain the stock in equilibrium.

Y_E yield when the stock is in equilibrium.

Eq. (4) demonstrates that the relation between equilibrium yield and equilibrium biomass is a parabola, i.e. Y_E is a parabolic function of B_E as shown in Figure 4. The parabolic production curve has the intercepts with horizontal axis at BE = 0 and

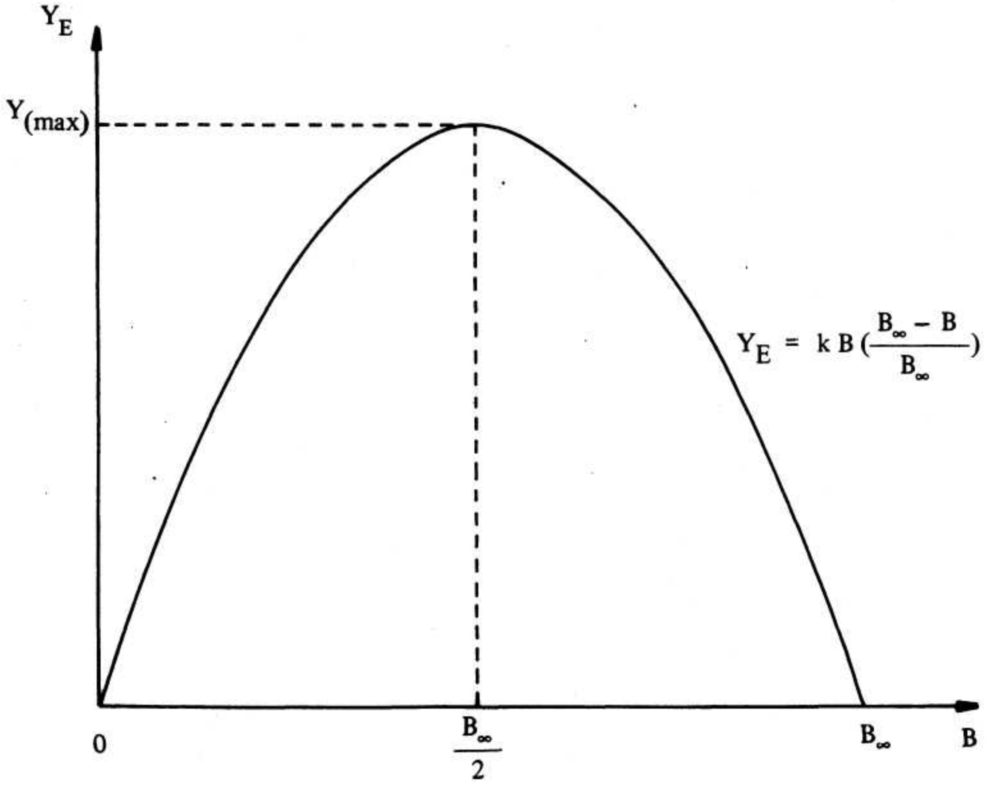

Figure 4. Equirilibrium yield (Y_E) against biomass

$B_E = B_\infty$. To obtain maximal/minimal of this curve, basic calculus can be employed, i.e. by differentiating Eq. (4) and equating to zero resulting

$$\frac{dY_E}{dB_E} = k - 2\frac{k}{B_\infty} B_E = 0$$

$$B_{(opt)} = \frac{B_\infty}{2}$$

substituting the value of B_∞ into Eq. (4) giving

$$Y_{(max)} = k\frac{B_\infty}{2} - \frac{k}{B_\infty}(\frac{B_\infty}{2})^2$$

$$Y_{(max)} = k\frac{B_\infty}{4}$$

As a result, the maximum equilibrium yield or MSY is derived when the biomass is exactly half of the maximum equilibrium biomass, and it is equal to one-quarter of the maximum biomass multiplied by the instantaneous rate of increase at very low level of biomass ($MSY = \frac{kB_\infty}{4}$).

2. Application/Fitting to Data

It is desirable to use method of fitting this model to the observed data, which makes the most effective use of the observations, resulting conclusions of useful advice and on the contrary avoiding of misleading guidance.

This numerical example is freely modified from RICKER (1975) which illustrates the fitting of the Graham's method, given the value of B_∞ and equilibrium fishing effort (p.312). An equilibrium conditions of a fishery was characterized by Y = 40 000 tons/year, of which 30 000 tons were fish of vulnerable size at the beginning of the year. From mark-recapture experiment, the rate of exploitation was found to be 30 percent. The catchable stock present at the beginning of the year was defined to be 30 000/0.30 = 100 000 tons. As the fishery was in steady state conditions, this represents also the equilibrium vulnerable stock, B_E. The rate of fishing, F_E was equal to 40 000/100 000 = 0.40, and this must also be the natural logistic growth rate, i.e. rate of recruitment plus rate of growth less rate of natural mortality.

Catch per unit effort was currently known as 10 tons/boat-day. But, a few years earlier, soon after a long of no-fishing period, catch was 22 tons/boat-day. Considering that Y/f (catch per unit effort) is proportional to stock (CPUE as an index of relative abundance), therefore

$$\frac{22}{10} = \frac{B_\infty}{B_E}$$

$$B_\infty = 22/10 \times 100\,000 = 220\,000$$

tons. Substituting this value of B_∞ into Eq. (4) we get

$$40\ 000 = k \times 10\ 000(\frac{220\,000 - 100\,000}{220\,000})$$

from which k = 0.77. Yield as a function of biomass in the steady state condition of this fishery can be expressed as

$$Y_E = 0.77\ B_E - \frac{0.77}{20\,000} B_E^2$$

3. Relation of CPUE to Fishing Effort - SCHAEFER's Method

So far the model of Graham may not directly helful. By a mathematical manipulation, SCHAEFER (1954) was successfully modified the model in terms of directly useful to fishery managers and at the same time it could be fitted using the real data of catch, abundance, and number of fishing easily and routinely collected by the same managers (PITCHER & HART 1982).

We can define the fish catch per unit effort at equilibrium, U_E as

$$U_E = Y_E/f \quad \ldots \quad (5)$$

where / is fishing effort. The unit chosen for expressing effort do not matter as long as they remain consistent. In so far as we can define yield as biomass times the rate of fishing times catchability

$$Y_E = f\,q\,B_E \quad \ldots \quad (6)$$

from Eq. (5) and Eq. (6) we can express that

$$U_E = f\,q\,B_E/f = q\,B_E$$

and can therefore express

$$B_E = U_E/q$$

i.e., stock size expressed as CPUE over catchability. Sinse the relationship is true only at equilibrium conditions, it cannot really be used to predict stock size when data of CPUE and catchability coefficient are available. This equation just demonstrates the fact that CPUE will change at different biomass level. The trick recognized by SCHAEFER is to substitute this new value for B and divided by U_E in Eq. (4) to get, for the SCHAEFER's model

$$f\,q\frac{U_E}{q} = \frac{U_E}{q}\left(\frac{B_\infty-(U_E/q)}{B}\right)$$

divided by U_E

$$f = \frac{k}{q}\left(1 - \frac{U_E}{qB_\infty}\right)$$

as $qB_\infty = U_\infty$, then

$$f = \frac{k}{q}\left(1 - \frac{U_E}{U_\infty}\right)$$

which can be easily expanded and rearanged to solve for U_E, giving

$$U_E = U_\infty - \left(\frac{q}{k}U_\infty\right) f \quad \ldots \quad (7)$$

Eq. (7) shows the general form of a linear regression of CPUE as a function of fishing effort *f*, in the form of $y = a + bx$, where $a = U$ and $b = -\frac{q}{k}U_\infty$. Graphically, Eq. (7) can be illustrated in Figure 5 which describes a useful expression showing the relationship between CPUE and fishing effort.

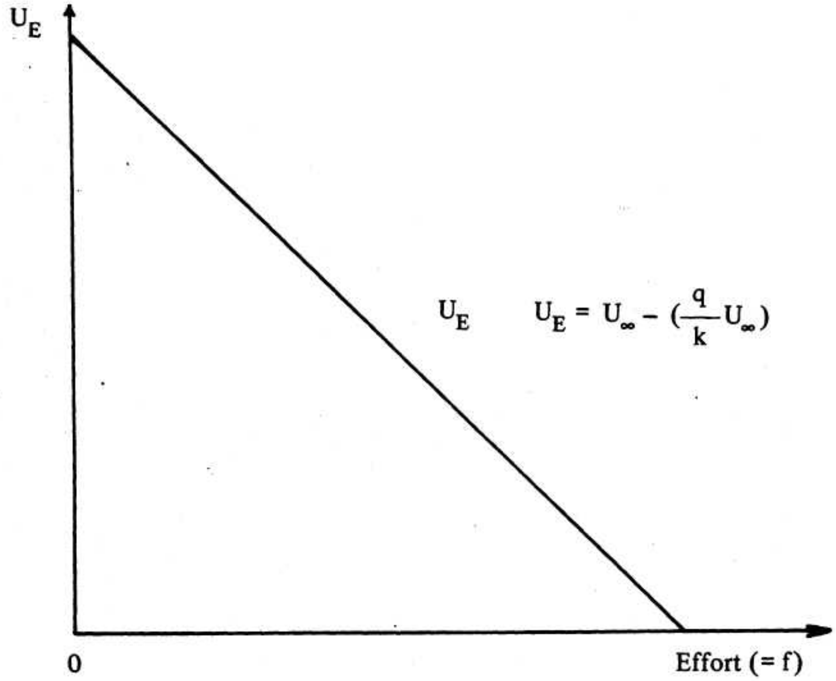

Figure 5. Catch per unit effort against effort.

4. Relation of Equilibrium Yield and Fishing Effort - SCHAEFER's Method

We use the results of the regression fitting of CPUE and fishing effort *f* in the final stage which purport to give the fishery manager exactly what be wanted, i.e. by relating fishing effort directly to yield.

Since $Y_E = U_E f$ by definition, we can get the SCHAEFER's model from Eq. (7) as

$$Y_E = U_\infty f - \left(\frac{q}{k} U_\infty\right) f^2 \quad \ldots \quad (8)$$

i.e. yield in equilibrium is a parabolic function of effort, which in general can be expressed by $y = af - bf^2$. By employing simple basic calculus the maxima and minima of the curve can be determined :

$$\frac{dy}{df} = a - 2bf = 0$$

$$f_{(opt)} = \frac{a}{2b} \quad \ldots \quad (9)$$

$$Y_{(max)} = a\,\frac{a}{2b} - b\,\frac{a^2}{4b^2}$$

$$Y_{(max)} = \frac{a^2}{4b} \quad \ldots \quad (10)$$

where $a = qB_\infty = U_\infty$ and $b = \frac{q}{k} U_\infty = \frac{q^2}{k} B_\infty$.

The maximum equilibrium yield or MSY and the optimum rate of fishing which produce the MSY simply can be obtained from the parabolic relationship between equilibrium yield and equilibrium fishing effort, as depicted in Figure 6.

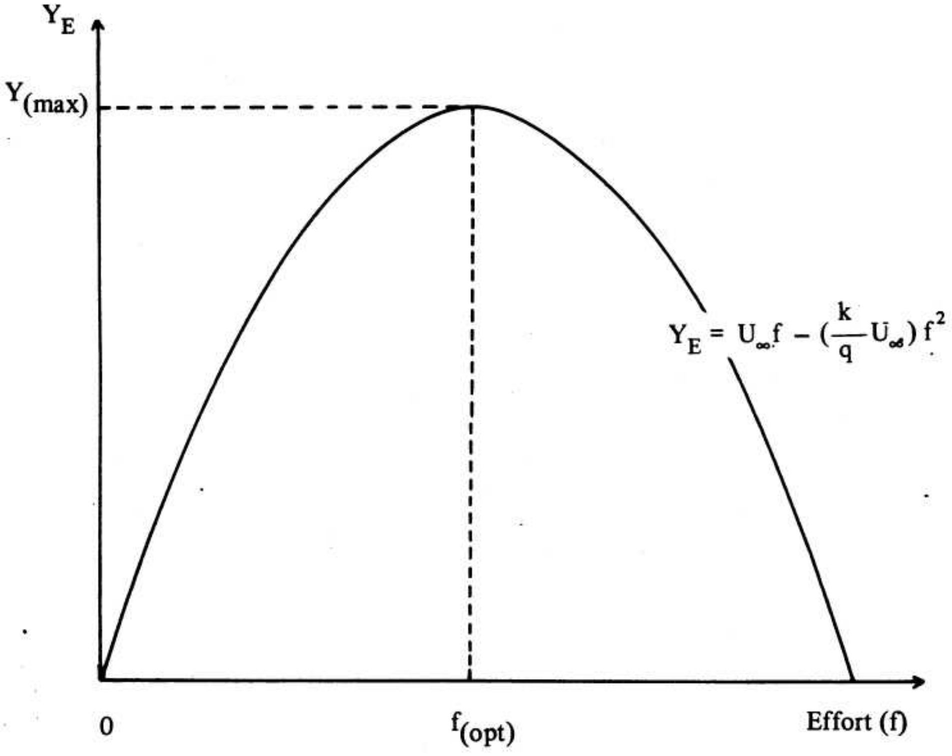

Figure 6. Equilibrium yield against fishing effort.

5. Numerical Example of Schaefer's Method

One approach to fitting data to this method is by manipulating the basic data, i.e. usually the annual catch and effort statistics, in such away that the procedure becomes a matter of fitting a simple curve to pair of values derived from these data, e.g. the CPUE in a given year and the effort of that year, and the yield versus the effort of the same year.

Let us take a look at the data of lemuru (oil sardines), *Sardinella longiceps,* of the Bali Strait as demonstrated by SUJASTANI & NURHAKIM (1982).

Tabel 1. Yield in tons, fishing effort in unit of purse-seiner, and yield per unit effort of lemuru (oil sardines), *Sardinella longiceps,* in the Bali Strait.

Year	Yield (tons)	Effort (unit of purse-seiner)	CPUE (Y/f) (ton/purse-seiner)
1974	6 380	17	375.3
1975	22 900	70	327.1
1976	35 204	126	279.4
1977	45 506	193	235.8
1978	27 915	228	122.4
1979	31155	304	102.5
1980	25 701	237	108.4

The yield (column 2) and the fishing effort (column 3) for each year are known and modified from fisheries statistics published by East Java and Bali Fisheries Agencies. There are divided to obtain the yield per unit effort (column 4), considered as an index of population abundance present each year.

Eq. (7) indicates the way to fit a curve to the lemuru data, i.e. by regressing $U_E (= Y_E/f)$ on /. The estimate of the functional regression of U_E on / is as follows:

$$U_E = 400.1 - 1.06 f$$

By substituting $a = 400.1$, and $b = 1.06$ into Eq. (9) optimum fishing effort can be estimated as

$$f_{(opt)} = \frac{400.1}{2 \times 1.06} = 188.7$$

$$f_{(opt)} = 189$$

The estimation of the maximum yield can be carried out by putting the values of *a* and *b* to Eq. (10)

$$Y_{(max)} = \frac{(400.1)^2}{4 \times 1.06} = 37\ 754.7$$

In conclusion, from the data illustrated in Table 1, MSY is estimated as 37 755 tons/year with estimation of optimal fishing effort of 189 units purse-seiner. The curves of the two relationships, i.e. CPUE vs. effort and Yield vs. effort can be illustrated in Figure 7.

CONCLUDING REMARKS

In general, the surplus production models require only simple data containing of one independent variable *t* (time), and four dependent variables, i.e. four function of time. Those are the population biomass B(t) with typical unit in ton, the rate of fishing effort *f(t)* in boat-day /year, the rate of catch *Y(t)* in ton/year, and the catch per unit effort *U(t)* in ton/boat-day. Besides, there are three parameters: the natural growth rate *k,* the carrying capacity B_∞, and the catchability coefficient *q.*

The axioms of the models consist of three equations:

$$\frac{db}{dt} = kb\left(1 - \frac{B}{B_\infty}\right) - 7 \quad \ldots \ (11)$$

i.e. the total growth rate of population biomass equals its natural logistic growth rate minus the catch rate;

$$Y = q\,f\,B \quad \ldots \quad (12)$$

i.e. the catch rate is directly proportional to the effort rate and the available biomass with the constant of proportionality is *q* (the catchability coefficient);

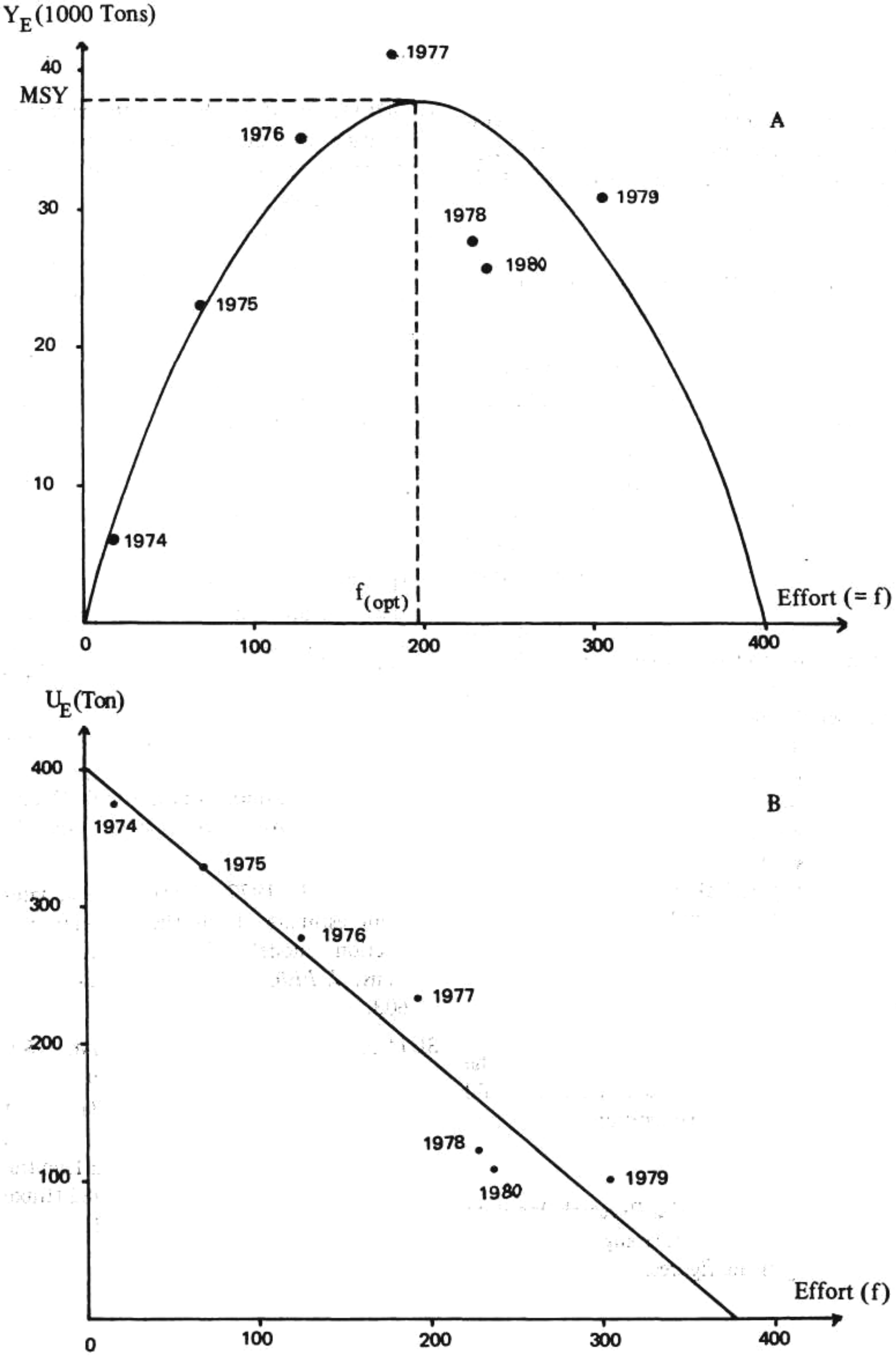

Figure 7. Graham-Schaefer model of the lemuru in Bali Strait.
A. Y_E vs. Effort B. U_E vs. Effort

$$U = q B \quad \ldots \quad (13)$$

i.e. the catch per unit effort itself proportional to the biomass alone. Actually, Eq. (12) and (13) imply that if $f \neq 0$, then

$$U = Y/f \quad \ldots \quad (14)$$

SCHNUTE (1977) points out that Eq. (14) should be the axiom, instead of Eq. (13). But, Eq. (14) is meaningful only when $f \neq 0$, while Eq. (13) is meaningful even when $f = 0$. From the Eq. (13) can be concluded that the CPUE, in general, is not zero even if the effort itself is zero. Accordingly, Eq. (13) suggests the correct interpretation for U, that is to say U is *potential* CPUE, namely, this potential is actualized only when fishing takes place, that is, when $f \neq 0$.

The main practical benefit of the surplus production models is that they require no demanding data, but catch and effort data over serial years. MSY is temptingly easy to calculate, in fact require no biologists to be employed in the fishery, and managers do not even have to get their feet and hands we in doing investigation on the actual fish (PITCHER & HART 1982). In contrast with their practical advantages as well as their attractive simplicity, these models ignore the real important biological processes that in fact generate the biomass of the population.

For this reason, the use of these unmodified simple production models in the management of. exploited fish stock should be employed with great caution.

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REFERENCES

GRAHAM, M. 1935. Modern theory of exploiting a fishery and application to North Sea trawling. *J. Cons, Int. Explor. Mer* 10: 264-274.

PIELOU, E.C. 1974. *Population and community ecology, Principles and methods.* Gordon and Breach Sci. Publ., New York. 424 pp.

PITCHER, T.J., and P.J.B. HART. 1982. *Fisheries ecology.* The Avi Publ. Co.,Inc., Westport, Connecticut. 414 pp.

RICKER, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull Fish. Res. Board Can.* 191: 382p.

SCHAEFER, M.B. 1954. Some aspects of the dynamics of population important to the management of the commercial marine fisheries. *Inter-Am. Trop. Tuna Comm. Bull* (2) : 27-56.

SCHAEFER, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. *Inter-Am. Trop. Tuna Comm. Bull 2* : 247-268.

SCHNUTE, J. 1977. Improved estimates from estimates from the Schaefer production model: theoritical considerations. *J. Fish. Res. Board Can.* 34 : 583-603.

SUJASTANI, T., and S. NURHAKIM. 1982. The stock assessment of Lemuru (Oil sardines), *Sardinella longceps* in Bali Strait (in Indonesia with Abstract in English). *In:* Prosiding Seminar Perikanan Lemuru, Banyuwangi, 18-21 Januari 1982 (Buku II), Puslitbangkan, Jakarta: 1-11.