Universidade federalde Pernambuco

## Centro de Tecnologia e Geociências

DEPARTAMENTO DE OCEANOGRAFIA

Biologia populacional de Pomacanthus paru (Teleostei: Pomacanthidae) e análise da sustentabilidade de captura do bycatch de peixes ornamentais.


Caroline Vieira Feitosa

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Caroline Vieira Feitosa

Tese submetida ao curso de Doutorado do
Programa de Pós Graduação em Oceanografia da Universidade Federal de Pernambuco, como requisito para obtenção do título de Doutor em Oceanografia.

Orientadora: Drå M aria Elisabeth de Araújo Co-Orientadora: Dra Beatrice Padovani Ferreira

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# Biologia populacional de Pomacanthus paru (Teleostei: Pomacanthidae) e análise da sustentabilidade de captura do bycatch de peixes ornamentais. 

Caroline Vieira Feitosa

Tese submetida em 11 de fevereiro de 2009 ao curso de Doutorado do Programa de Pós Graduação em Oceanografia da Universidade Federal de Pernambuco, como requisito para obtenção do título de Doutor em Oceanografia e aprovada pela seguinte banca examinadora:


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Dedico esta tese a minha querida vó Luda (in memoriam), por todo o amor e pela alegria ao vivenciar minhas conquistas acadêmicas, mesmo torcendo a distância...

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## Resumo

Pomacanthus paru tem grande importância para o aquarismo brasileiro, além de ser a segunda espécie marinha mais exportada desde 2000. Os objetivos desta pesquisa foram os seguintes: (a) descrever a biologia reprodutiva e determinar a idade e o crescimento de P. paru, (b) analisar a diversidade genética de P. paru e $P$. arcuatus a partir do DNA mitocondrial, (c) registrar as espécies de peixes ornamentais capturadas como bycatch através da pesca com armadilhas e propor uma metodologia para determinar a sustentabilidade de captura das principais espécies ornamentais marinhas no Brasil. Amostragens semanais foram realizadas durante o período de março 2006 a fevereiro 2007. Os exemplares menores de 15 cm foram comprados de coletores de peixes ornamentais. Os peixes foram medidos, pesados, e as gônadas e os otólitos foram removidos. Amostras de músculo e do fígado foram armazenadas para o estudo genético. A região 16 S rDNA foi amplificada e sequências do ADN mitocondrial foram utilizadas para a análise dos haplótipos. Para a proposição da metodologia de sustentabilidade de captura, cada espécie foi avaliada segundo dois grupos de critérios: (1) vulnerabilidade relativa à captura pelas armadilhas; (2) resiliência da população relacionada à mortalidade devido à pressão pesqueira. No total, 236 indivíduos foram analisados, sendo 139 fêmeas, 86 machos e 11 que não tiveram o sexo definido. P. paru é uma espécie gonocorística, que se reproduz ao longo do ano, com as fêmeas apresentando dois picos de desova (Fevereiro-M arço/Setembro-Outubro). As fêmeas foram mais abundantes em todos os meses, exceto em outubro. $0 \mathrm{~L}_{50}$ é atingido aos 30 cm para as fêmeas e 35 cm para os machos. A idade dos indivíduos amostrados de P. paru variou de 1 a 27 anos. P. paru atinge o comprimento máximo lentamente e tem um longo ciclo de vida. Para P. paru seis haplótipos foram encontrados, enquanto em P. arcuatus apenas um, incluindo os espécimes do Caribe. Foram registradas como bycatch, 19 espécies pertencentes a 10 famílias. As espécies cujas capturas foram menos sustentáveis foram Holacanthus tricolor, H. ciliaris, Chaetodon striatus e P. paru. O manejo de P. paru deve incluir medidas baseadas no tamanho de primeira maturação sexual, bem como nos parâmetros de crescimento aqui estabelecidos. Os resultados relacionados à genética representam um primeiro passo para se compreender as estruturas populacionais de espécies tão próximas filogenética e ecologicamente como P. paru e P. arcuatus. A nova metodologia aqui proposta deverá ser uma ferramenta útil e alternativa para o manejo e avaliação da sustentabilidade de captura das espécies oriundas de pescarias multi-específicas, com poucos dados disponíveis e que ocorrem em áreas de alta riqueza, como os recifes.

Palavras-chave: Pomacanthus paru, reprodução, idade, crescimento, bycatch


#### Abstract

Pomacanthus paru presents great importance in the Brazilian aquarium trade, being the second most exported species since 2000. The aims of this research were (a) to describe the reproductive biology and to determine the age and growth, (b) to analyze the genetic diversity of P. paru and P. arcuatus from mt-DNA, (c) to record ornamental fish bycatch and to propose a methodology to assess the catch sustainability of ornamental fish bycatch from the major Brazilian families in the aquarium trade. Weekly samplings were performed from M arch 2006 to February 2007. Individuals smaller than 15 cm were bought from collectors of ornamental fish. The fish were measured, weighed and the gonads and otoliths were removed. Samples of tissue from muscle and liver were stored for the genetic study. A region of the 16 S rDNA was amplified and sequences of the mtDNA were used for haplotypes analysis. To assess the catch sustainability of ornamental fish bycatch, each species was assessed based on two groups of criteria: (1) relative vulnerability to capture; and (2) population resilience regarding mortality due to fishing efforts. Of the 236 individuals sexed, 139 were female, 86 were male and 11 were indefinite. P. paru is a gonochoric species, which is reproductive activite all year-round, with females presenting two spawning peaks (February-March/September-October). Females were more abundant at all months, except October. The $\mathrm{L}_{50}$ is reached at 30 cm for females and 35 cm for males. The ages of the fish in the sample varied from 1 to 27 years. P. paru attains its maximal size slowly and has a long lifespan. For P. paru six haplotypes were recorded, while only one was registered for P. arcuatus, including Caribbean species. Nineteen species from 10 families were recorded. The species least likely to have sustainable catch rates were Holacanthus tricolor, H. ciliaris, Chaetodon striatus and P. paru. The management of this latter species should include measures based on its size at maturity as well as in growth parameters established in this research. The considerations regarding genetic represent a first step toward understanding the population structures of species as phylogenetically and ecologically close as Pomacanthus paru and P. arcuatus. The proposed methodology is a useful alternative for management efforts and the assessment of catch sustainability in newlydeveloped multi-species fisheries with limited available data, which occur in areas of high species richness such as reefs.


Key-words: Pomacanthus paru, reproduction, age, growth, bycatch

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## Introdução

Os peixes da família Pomacanthidae, conhecidos como peixes-anjo, possuem o corpo alto e comprimido lateralmente, algumas vezes quase circular (Cervigón, 1993). São bastante parecidos com os peixes borboleta da família Chaetodontidae (Smith \& Heemstra, 1991) e Ephippidae (Menezes \& Figueiredo, 1985). Apresentam boca pequena, terminal e protátil, extremidade inferior do pré-opérculo com um forte e largo espinho e escamas ctenóides pequenas (Menezes \& Figueiredo, 1985; Cervigón, 1993). São de tamanho médio e possuem padrões de colorido variados e contrastantes, diferindo notadamente entre os jovens e adultos (Nelson, 1994). É uma das famílias mais procuradas pelos aquaristas, sendo o colorido a principal razão desta popularidade (Allen et al., 1998).

Os pomacantídeos distribuem-se por todas as latitudes tropicais e subtropicais. Estão geralmente associados às águas costeiras com desenvolvimento de recifes ou pedras (Cervigón, 1993; Allen, 1979) em profundidades inferiores a 20 m e raramente abaixo dos 50 m (Nelson, 2006). A família Pomacanthidae possui 82 espécies e oito gêneros (Nelson, 2006) com mais da metade das espécies sendo pertencentes aos gêneros Centropyge e Pomacanthus (Nelson, 1994). Destas, 89\% do total ocorrem nos oceanos Índico e Paćífico. No Atlântico, a maioria das espécies ocorre na porção oeste deste oceano, comumente referidas para o mar do Caribe. Apenas uma espécie é exclusiva do oeste da África e outra do Atlântico Central (Ascenção). Para Austrália são registradas 24 espécies, sendo considerado o país com a maior diversidade de pomacantídeos (Allen et al., 1998). O gênero Pomacanthus está representado por 13 espécies, além de 4 híbridos (Allen et al., 1998). Estas espécies podem ser encontradas em águas rasas em regiões de recifes e pedras, em grupos ou isoladamente (Menezes \& Figueiredo, 1985).

Estudos sobre a ecologia dos pomacantídeos são numerosos (e.g. Randall \& Hartman, 1968; Hourigan et al., 1989; Roberts et al., 1992; Sakai \& Kohda, 1997; Kuwamura, 1998;

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Kulbick \& Sarramégna, 1999; Sazima et al., 1999; Aburto-Oropeza et al., 2000; Hamagushi et al., 2002; Bellwood et al., 2004). Entretanto, informações sobre seus aspectos populacionais como idade, crescimento e longevidade são relativamente escassas. A única espécie da família avaliada quanto à idade e o crescimento foi Pomacanthus imperator, onde as escamas foram utilizadas para determinação destes parâmetros (Chung \& Woo, 1999). Os pomacantídeos foram geneticamente estudados principalmente no Atlântico Sul. Foram realizadas análises com marcadores citogenéticos (Galetti et al., 2006), enzimáticos (Chung \& Woo, 1998), e mitocondriais (Bellwood et al., 2004; Bowen et al., 2006), principalmente com o objetivo de responder questões taxonômicas e evolutivas. Uma vez que os pomacantídeos encontram-se sob forte pressão pesqueira, informações genéticas continuam sendo necessárias a fim de obter uma medida acurada da biodiversidade (Affonso \& Galetti, 2007).

Dentre as espécies de pomacantídeos, aquelas do gênero Centropyge são as mais estudadas principalmente no que se refere ao desenvolvimento gonadal e comportamento reprodutivo (Bauer \& Bauer, 1981; M oyer et al., 1983; Aldenhoven, 1986; Sakai, 1986; Sakai \& Kohda, 1997). Alguns estudos foram realizados enfocando aspectos reprodutivos para os gêneros Holacanthus e Pomacanthus, tais como tamanho de primeira maturação sexual, fecundidade $(\mathrm{n}=2)$ (Aiken, 1983) e época de desova ( $\mathrm{n}=21$ ) (Munro et al., 1973). Porém, o tamanho amostral de P. paru foi considerado pequeno pelos autores para realizar comparações com outras pesquisas.

Os principais componentes da dieta destes indivíduos são as esponjas e algas (Randall, 1967; Randall \& Hartman, 1968). Quando jovens, complementam sua dieta retirando ectoparasitas de peixes de maior porte (Allen et al., 1998; Sazima et al., 1999). São espécies que normalmente formam pares, entretanto pequenos haréns foram registrados (Allen et al., 1998).

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A espécie P. paru (Bloch, 1787) distribui-se desde a Flórida até o sudeste do Brasil. É relativamente comum no litoral brasileiro (Menezes \& Figueiredo, 1985), sendo mais abundante na região Sudeste quando comparada a Nordeste (Ferreira et al., 2004). Ocorre em profundidades entre 5 a 100 m (Allen, 1979). Atinge cerca de 40 cm de comprimento e quando adulto, possui o corpo enegrecido, tendo a cabeça uma coloração mais clara e as margens das escamas amareladas. Nos jovens o corpo é totalmente negro com cinco faixas amarelas verticais (Allen et al., 1998). O jovem de P. paru é muito parecido com a espécie P. arcuatus, diferindo no número de raios e principalmente na nadadeira caudal, que é truncada posteriormente em P. arcuatus e arredondada em P. paru (M enezes \& Figueiredo, 1985).

O conhecimento do ciclo de vida de espécies como P. paru, que são extraídas diretamente do ambiente natural para o aquarismo, é fundamental para a sua conservação. Embora P. paru não se encontre na lista de espécies ameaçadas de extinção da IUCN (IUCN, 2008), ela é muito explorada no Brasil pela indústria aquariofilista (Monteiro-Neto et al., 2003). Devido à pressão pesqueira sobre os jovens, a abundância de P. paru em alguns pontos próximo a Guarapari (ES) está inversamente relacionada com a distância da costa, enquanto o número de adultos não difere (Gasparini et al., 2005). A abundância desta espécie é significativamente maior em áreas protegidas (Gasparini et al., 2005). Nos últimos anos, P. paru vem sendo listada como a segunda espécie mais exportada pelo Brasil (Monteiro-Neto et al., 2003; IBAM A, 2007). Entre o período de 1995 a 2000, somente o Estado do Ceará exportou 22.969 espécimes de P. paru (Monteiro-Neto et al., 2003) e, em 2007, 13.422 indivíduos foram exportados pelo Brasil (IBAMA, 2007). O ordenamento destas espécies vem sendo realizado através de uma instrução normativa do IBAMA (IN56/04), onde foram estabelecidas cotas específicas de exportação. Atualmente a cota de captura deste indivíduo é de 2.500 indivíduos/ano/empresa (IBAM A, 2004).

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Grande parte das espécies marinhas comercializadas no aquarismo é de origem tropical e extraída dos recifes. 0 potencial para a sobrexploração desta atividade é alto, uma vez que indivíduos juvenis, na maioria das vezes, menores que 10 cm de comprimento e de muito valor são retirados em grandes quantidades (Wood, 2001). Além dos efeitos diretos causados pela extração de peixes para o aquarismo é consenso os danos provocados no ecossistema marinho pelas práticas destrutivas utilizadas para coletar estes organismos (Wood, 1985, 2001; Nottingham et al., 2005). Somada à pressão pesqueira sofrida por esta espécie por meio do aquarismo, P. paru é constantemente capturada como bycatch em armadilhas de pesca no Nordeste do Brasil (Feitosa et al., 2008). As armadilhas têm sido responsáveis pelo colapso de muitos recursos recifais (Wolff et al., 1999), principalmente devido à pouca seletividade do petrecho. No caso específico de P. paru, espécimes de 15 a 40 cm de comprimento foram pescadas pelas armadilhas (Feitosa et al., 2008). Dentre os peixes ornamentais capturados por este petrecho, aqueles dos gêneros Acanthurus, Chaetodon, Bodianus, Holacanthus e Pomacanthus são frequentemente os mais capturados (Garrisson et al., 1994; Wolff et al., 1999).

A sobrexploração de espécies de peixes marinhos pela captura para fins ornamentais e a destruição de habitats são apontados como os principais problemas gerados pelo aquarismo. Portanto, recomenda-se que sejam realizados levantamentos estatísticos sobre o número de peixes ornamentais envolvidos no mercado, além de estudos sobre a biologia e dinâmica populacional destas espécies (Andrews, 1990; Edwards \& Shepherd, 1992; Wood, 2001).

A demanda global por peixes ornamentais tem resultado no aumento direto dos índices de coletas nos estoques naturais (Ogawa \& Brown, 2001). Pouco se sabe sobre a dinâmica populacional destas espécies, pois a quantidade de espécies exportadas é baseada em entrevistas com coletores que muitas vezes não falam a realidade. A situação das populações de peixes recifais é inconclusiva, principalmente devido a variações sazonais

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naturais, bem como as alterações no esforço de pesca para um dado ano de estudo (Ogawa \& Brown, 2001).

Nas últimas reuniões técnicas, promovidas pelo IBAM A, sobre a exploração de peixes ornamentais marinhos, foi enfatizada a carência de pesquisas sobre a biologia e dinâmica populacional das principais espécies exportadas pelo Brasil (e.g. Holacanthus ciliaris e Pomacanthus paru) (IBAMA, 2000, 2003). Desta forma, espera-se que os resultados obtidos na presente pesquisa forneçam subsídios fundamentais à criação de medidas de regulamentação, bem como proporcionem dados necessários ao adequado manejo de suas populações.

## Referências

Aburto-Oropeza, O.; Sala, E.; Sánchez-Ortiz, C. 2000. Feeding behavior, habitat use \& abundance of the angelfish Holacanthus passer (Pomacanthidae) in the Southern Sea of Cortés. Environmental Biology of Fishes, 57: 435-442.

Aiken, K. 1983. The biology, ecology \& bionomics of the butterfly \& angelfishes, Chaetodontidae. p. 155-165. In: Munro, J. L. (ed). Caribbean coral reef fisheries resource. Iclarm studies \& reviews 7. M anila, Philippines.

Affonso, P. R. A. M.; Galetti Jr., P. M. 2007. Genetic diversity of three ornamental reef fishes (Families Pomacanthidae \& Chaetodontidae) from the Brazilian coast. Brazilian Journal of Biology, 67: 925-933.

Aldenhoven, J. M. 1986. Different reproductive behavior strategies in sex changing coral reef fish Centropyge bicolor (Pomacanthidae). Australian Journal of M arine \& Freshwater Research, 37: 353-360.

Allen, G. R. 1979. Butterfly and angelfishes of the world. M ergus Publishers, M elle.
Allen, G.R.; Steene, R.; Allen, M. 1998. A guide to angelfishes \& butterflyfishes. Odyssey Publishing, USA/ Tropical Reef Research, Australia.

Biologia populacional de Pomacanthus paru (Teleostei: Pomacanthidae) e análise ....

Andrews, C. 1990. The ornamental fish trade \& conservation. Journal of Fish Biology, 37: 5359.

Bauer, J. A.; Bauer, S. E. 1981. Reproductive biology of pigmy angelfishes of the genus Centropyge (Pomacanthidae). Bulletin of M arine Science, 31: 495-513.

Belwood, D. R.; van Herwerden, L.; Konow, N. 2004. Evolution \& biogeography of marine angelfishes (Pisces: Pomacanthidae). M olecular Phylogenetics \& Evolution, 33: 140-155.

Bowen, B. W.; Muss, A.; Rocha, L. A.; Grant, W. S. 2006. Shallow mtDNA Coalescence in Atlantic Pygmy Angelfishes (Genus Centropyge) Indicates a Recent Invasion from the Indian Ocean. Journal of Heredity, 97: 1-12.

Cervigón, F. 1993. Los peces marinos de Venezuela. Fundación Científica de Los Roques, Venezuela.

Chung, K. C.; Woo, N. Y. S. 1998. Phylogenetic relationships of the Pomacanthidae (Pisces: Teleostei) inferred from allozyme variation. Journal of Zoology, 246: 215-231.

Chung, K.C.; Woo, N.Y.S. 1999. Age and growth by scale analysis of Pomacanthus imperator (Teleostei: Pomacanthidae) from Dongsha Isllands, southern Chine. Environmental Biology of Fishes, 55: 399-412.

Edwards, A.J.; Shepherd, A.D. 1992. Environmental implications of aquarium-fish collection in the M aldives, with proposals for regulation. Environmental Conservation, 19: 61-72.

Feitosa, C. V.; Ferreira, B. P.; Araújo, M. E. 2008. A rapid new method for assessing sustainability of ornamental fish by-catch from coral reefs. M arine and Freshwater Research, 59: 1092-1100.

Ferreira, C.E.L.; Floeter, S.R.; Gasparini, J.L.; Joyeux, J.C.; Ferreira, B.P. 2004. Trophic structure patterns of Brazilian reef fishes: a latitudinal comparison. Journal of Biogeography, 31: 10931106.

Galetti Jr., P. M.; M olina, W. F.; Affonso, P.A. M.; Aguilar, C. T., 2006. Assessing genetic diversity of Brazilian reef fishes by chromosomal and DNA markers. Genetica, 126: 161-177.

Biologia populacional de Pomacanthus paru (Teleostei: Pomacanthidae) e análise ....

Garrison, V. H.; Rogers, C. S.; Beets, J. 1994. Of reef fish, overfishing and in situ observations of fish traps in St. John, U. S. Virgin Islands. Revista de Biologia Tropical, 46: 41-59.

Gasparini, J. L.; Floeter, S. R.; Ferreira, C. E. L.; Sazima, I. 2005. Marine ornamental trade in Brazil. Biodiversity Conservation, 14: 2883-2899.

Hamagushi, Y.; Sakai, Y.; Takasu, F.; Shigesada, N. 2002. M odelling spawning strategy for sex change under social control in haremic angelfishes. Behavioral ecology, 13: 75-82.

Hourigan, T. F.; Stanton, F. G.; M otta, P. J.; Kelley, C. D.; Carlson, B. 1989. The feeding ecology of three species of Caribbean angelfishes (family Pomacanthidae). Environmental Biology of Fishes, 24: 105-116.

IBAMA. 2000. Projeto Peixes ornamentais marinhos: ordenamento da captura e comercialização. Relatório final, Tamandaré-PE.

IBAMA. 2003. Relatório da reunião sobre a explotação de peixes ornamentais marinhos no Brasil. Fortaleza- CE.

IBAM A. 2004. Instrução normativa № 14, de 18 de fevereiro de 2004.
IBAM A. 2007. Peixes ornamentais marinhos: Estatística de exportação por espécie para 2007. http://www.ibama.gov.br/recursos-pesqueiros/wp-content/files/quantidades _exportadas _ 2007 _marinho.pdf

IUCN 2008. 2008 IUCN Red List of Threatened Species. $\varangle w w w$. iucnredlist.org>. Downloaded on 26 January 2009.

Kulbicki, M ; Sarramégna, S. 1999. Comparison of density estimates derived from a strip transect and distance sampling for underwater visual censuses: a case study of Chaetodonthidae e Pomacanthidae. Aquatic Living Resources, 12: 315-325.

Kuwamura, T. 1998. New aspects of sex change among reef fishes: recent studies in Japan. Environmental Biology of Fishes, 52: 125-135.

Biologia populacional de Pomacanthus paru (Teleostei: Pomacanthidae) e análise ....

Menezes, N.; Figueiredo, J. L. 1985. Manual de peixes marinhos do sudeste do Brasil. V. Teleostei (4). EDUSP, São Paulo, 105p.

M onteiro Neto, C.; Cunha, F. E. A.; Nottingham, M. C.; Araújo, M . E.; Rosa, I. L. \& Barros, G. M . L. 2003. Analysis of the marine ornamental fish trade at Ceará State, northeast Brazil. Biodiversity and Conservation, 12: 1287-1295.

Moyer, J. T.; Thresher, R. E.; Colin, P. L. 1983. Courtship, spawning and inferred social organization of American angelfishes (Genera Pomacanthus, Holacanthus and Centropyge; Pomacanthidae). Environmental Biology of Fishes, 9: 25-39.

Munro, J.L.; Gaut, V.C.; Thompson, R.; Reeson, P. 1973. The spawning seasons of Caribbean reef fishes. Journal of Fish Biology, 5: 69-84.

Nelson, J. S. 1994. Fishes of the world. John Wiley \& Sons Inc, USA. 600pp.
Nelson, J. S. 2006. Fishes of the world. John Wiley \& Sons Inc, USA. 622pp.
Nottingham, M. C.; Barreto, L. M.; Araujo, M . E.; M onteiro-Neto, C.; Cunha, F. E.; Rosa, I. M. L.; Alencar, C. A. G. 2005. A explotação de peixes ornamentais marinhos no Estado do Ceará, Brasil: captura, manutenção nas empresas e exportação. Boletim Técnico- Científico do CEPENE, 13: 53-73.

Ogawa, T.; Brown, C. L. 2001. Ornamental reef fish aquaculture \& collection in Hawaii. Aquarium Sciences and Conservation, 3: 151-169, 2001.

Randall, J. E. 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography (M iami), 5: 665-847.

Randall, J. E.; Hartman, W. D. 1968. Sponge-feeding fishes of the West Indies. Marine Biology, 1: 216-225.

Roberts, C. M.; Shepherd, A. R. D.; Ormond, R. F. G. 1992. Large-Scale Variation in Assemblage Structure of Red Sea Butterflyfishes and Angelfishes. Journal of Biogeography, 19: 239-250.

Biologia populacional de Pomacanthus paru (Teleostei: Pomacanthidae) e análise ....

Sakai, Y. 1986. Fecundity of female angelfish, Centropyge ferrugatus, independent of body size: field collection of spawned eggs. Ichthyological Research, 43: 186-189.

Sakai, Y.; Kohda, M. 1997. Harem structure of the protogyneous angelfish, Centropyge ferrugatus (Pomacanthidae). Environmental Biology of Fishes, 49: 333-339.

Sazima I.; M oura R.L.; Sazima, C. 1999. Cleaning activity of juvenile angelfish, Pomacanthus paru, on the reefs of the Abrolhos Archipelago, western South Atlantic. Environmental Biology of Fishes, 56, 399-407.

Smith, M. M.; Heemstra, P. C. 1991. Smith's sea fishes. Southern Book Publishers, Johanesburg, 1048p., 144pls.

Wolff, N.; Grober-Dunsmore, R.; Rogers, C. S.; Beets, J. 1999. Management implications of fish trap effectiveness in adjacent coral reef \& gorgonian habitats. Environmental Biology of Fish, 55: 81-90.

Wood, E. 1985. Exploitation of coral reef fishes for the aquarium trade, a report to the Marine Conservation Society UK, 129p.

Wood, E. 2001. Collection of coral reef fish for aquaria: global trade, conservation issues and management strategies. M arine Conservation Society, Herefordshire, UK.

Capítulo 1 - Reprodução do Paru preto Pomacanthus paru (Teleostei: Pomacanthidae) no nordeste do Brasil.


#### Abstract

Chapter 1* - Reproduction of the French Angelfish Pomacanthus paru (Teleostei: Pomacanthidae) from Northeastern Brazil.


* Capítulo em formato de artigo e padronizado de acordo com as normas da revista ICES Journal of M arine Science.

Reproduction of the French Angelfish Pomacanthus paru (Teleostei: Pomacanthidae) from Northeastern Brazil.

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#### Abstract

Pomacanthus paru is an important species for the Brazilian aquarium trade, being the second most exported. The aim of this study was to describe the reproductive biology of $P$. paru. Fish were caught as bycatch in trap fishery. Weekly samplings were performed from March 2006 to February 2007. Total length (TL), standard length (SL) and body weight (BW) were recorded. Gonadosomatic index (GSI) and batch fecundity were calculated. Individuals were sexed and the maturity stages were determined. The French angelfish is a gonochoristic fish and presents size dimorphism. Sex ratios were biased toward female at all months, except October. The L50 were different between sexes, being maturity reached at 30 cm for females and 35 cm for males. Pomacanthus paru is reproductively active throughout the year, with females presenting two distinct spawning peaks. This species is mainly targeted by the aquarium trade, but it is also caught as bycatch. Despite the determination of the size at maturity, this information is not relevant for the aquarium trade management, as most commercialized ornamental fish are juveniles under 10 cm in standard length. It can be suggested that conservationist issues should be based on capture per area and the establishment of protected areas.


Key words: Pomacanthus paru, sex ratio, size at maturity, size dimorphism, spawning season.
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## Introduction

Knowledge on fish reproduction is especially important for targeted species. Size at first maturity, reproductive behavior and fecundity are essential characteristics for the management of fisheries (Wootton, 1979; Jennings et al., 2001).

Pomacanthids, or angelfish, are among the most colorful and widely recognized group of reef fish (Thresher, 1982), and a favorite for divers and aquarists. Angelfish occur throughout tropical and subtropical seas and are associated with coral reefs. The biology of Pomacanthidae family has caused special concern among reef ichthyologists, particularly due to its habit of forming harems (Allen et al., 1998). The genera Centropyge and Geniacanthus (the smallest angelfish), are the most studied in terms of gonad development and reproductive behavior (Bauer and Bauer, 1981; Moyer et al., 1983; Aldenhoven, 1986; Sakai, 1986; Sakai and Kohda, 1997). The reproductive behavior of angelfish is relatively well known but there is little information on the spawning habits of Pomacanthus angelfish (Allen, 1979). Pomacanthus angelfish are known to be gonochoristic (Moyer et al., 1983; Thresher, 1984) but further studies are needed to state this for all members of the genus (Michael, 2004).

Pomacanthus paru is distributed from Florida, the Bahamas and northern Gulf of Mexico to Santa Catarina State - Brazil (Menezes et al., 2003). It is also reported for St. Paul's Rocks (Feitoza et al., 2003) and Ascension Island (Maugé, 1990) in the Central Atlantic and Gulf of Guinea. Maximal length is 41 cm (Cervigón, 1993). This species occurs in waters from 5 to 100 m , but juveniles and subadults are more common in shallow waters (Allen et al., 1998; Michael, 2004). The French angelfish is an omnivore. Sponges are its main food item, constituting nearly $75 \%$ of its diet (Randall, 1967). It appears that adult usually form stable pairs, although in areas where the fish is more common it is known to form small harems (Allen et al., 1998; Michael, 2004).

Most species collected for the Brazilian aquarium trade belong to the Pomacanthidae family (Araújo and Albuquerque Filho, 2005). Pomacanthus paru is an important species in this trade and has been one of the most exported species since 2000 (Araújo and Albuquerque Filho, 2005; Nottingham et al., 2000; Monteiro-Neto et al., 2003). During the period of 1995 and 2000, only the Ceará State (Northeastern Brazil) exported 22. 969 specimens of P. paru (Monteiro-Neto et al., 2003). This species is managed through a Federal Act (56/04) established in 2004 with the purpose of managing activity through the establishment of export quotas. Besides the impact from aquarium trade on juveniles, this species is frequently caught by traps. Trap fisheries catch a broad length range of ornamental species (e.g. Holacanthus ciliaris and Pomacanthus paru), including individuals that make up the breeding stock (Feitosa et al., 2008). There is no regulation for this type of fishery in Brazil.

Studies on reproduction are very important for fishery management (Fonteles Filho, 1989), as management decisions are based on reproductive parameters, such as size at maturity. There have been few studies on the sexuality, sexual maturity, fecundity (Aiken, 1983) and spawning season of pomacanthids (Munro et al., 1973). For $P$. paru the sample sizes in the two studies cited were very small (four and 21 individuals, respectively). Thus, there is no substantial information on the population structure of this species.

The aim of the present study was to describe the reproductive biology of the $P$. paru. The specific goals of the study were to investigate (a) gonad development, (b) spawning season, (c) gonad morphology and histology, (d) fecundity and (e) size at sexual maturity in order to provide useful information for the management of the fishery targeting this species.

## Materials and methods

## Sample collection

The fish were collected from commercial fishing boats of the fishing colony of Itamaracá Island located on Pilar beach ( $7^{\circ} 45.30^{\prime} \mathrm{S} 34^{\circ} 49.44^{\prime} \mathrm{W}$ ) (state of Pernambuco, Northeastern Brazil - Fig. 1). The specimens were caught as bycatch while trap fishing for the spotted goatfish (Pseudupeneus maculatus) and parrotfish (Sparisoma spp). In this fishery, traps are deployed unbaited next to reefs and hauled 6 hours later. Occasionally, depending on factors such as wind and currents, some traps are left for longer periods and only hauled after 48 hours.


Figure 1: Location of the sampled site.
Weekly samplings were carried out from March 2006 to February 2007. As individuals smaller than 15 cm are not caught by traps, they were bought from fish collectors between September 2006 and February 2007.

The fresh sampled fish were placed in polystyrene chests with ice and taken to the Laboratório de Nécton e Aquicultura of the Departamento de Oceanografia of Universidade Federal de Pernambuco. Total length (TL), standard length (SL) and body height $(\mathrm{BH})$ and weight $(\mathrm{BW})$ were recorded from the specimens to the nearest 1 mm and to the nearest 0.01 g . The gonadossomatic index (GSI) was used as an index of reproductive activity and was calculated as follows: $[\mathrm{GSI}=(\mathrm{GW} / \mathrm{BW}) \times 100]$, in which GW is the gonadal weight (g) and BW is the fish weight. For the batch fecundity analysis, 0.100 g of the ovary were removed and separated in glycerine with the aid of a brush and knife; and the hydrated oocytes in this sample were counted (Hunter and Macewicz, 1985a; Hunter and Goldberg, 1980; Vazzoler, 1996). Relative fecundity was expressed as the number of eggs/gram of ovary-free body weight. Oocyte diameter was measured under a microscope at 100 x with a video camera attachment, using the ImageLab software program (Softium).

## Sample processing

The gonads were dissected from the fish, weighed to the nearest 0.01 g , fixed in Bouin's solution for 24 h and transferred to $70 \%$ ethanol for later sectioning. The mid portion of the gonad was embedded in paraffin, following standard histological techniques. The paraffin blocks were sectioned transversely at $6 \mu \mathrm{~m}$ thickness by a rotary microtome. Duplicate slides were prepared for each tissue and stained with Mayer's hematoxylin-eosin, following standard histological procedures. Individuals were sexed and the maturity stages were determined adopting the stages proposed by Murphy and Taylor (1990), West (1990) and Yamaguchi et al. (2006) (Table 01). Sex and reproductive condition were determined for each individual based on histological evaluations under a microscope at $40-400 \mathrm{x}$ magnification.

116 Table 1: Macroscopic and histological stages used to describe ovaries and testes of
117 Pomacanthus paru based in Murphy and Taylor (1990), West (1990) and Yamaguchi et al. (2006).

Gonad stage by sex
Main characteristics
Females
Immature Difficult to determine sex macroscopically. Ovaries small and threadlike, transparent. Most advanced oocytes are at peri-nucleolus stage or yolk vesicle stage.

Maturing $\quad$ The gonads present reduced dimensions ( $\approx 6 \mathrm{~cm}$ in length and 1.80 cm in width). Ovaries varies in color from pink to pale yellow. Most oocytes are in early vitellogenesis stage. Oocytes in late vitellogenesis stage also can be seen. Besides, brown bodies are also observed.

Ripening $\quad$ Ovaries are yellow in color. An increase in blood vessels, volume and size of the structure are recorded. Most oocytes are in late vitellogenesis stage. Few oocytes are in early vitellogenesis stage. Brown bodies are also registered.

Spawning Gonads very developed. Ovaries coloration varies from yellow to orange. Migratory nucleus, hydrating or hydrated oocytes. Brown bodies recorded.

Resting Most advanced oocytes are at peri-nucleolus stage or yolk vesicle stage. Due to the diameter of the gonad and the thickness of the gonad wall, it was possible to differ the resting ovaries differ from the immature ones.

| Gonad stage by sex | Main characteristics |
| :---: | :---: |
| Males |  |
| Immature | Difficult to determine sex macroscopically. Testes small and threadlike, transparent. Testes with spermatogonia in the first spermatogenesis stage. |
| Maturing | Testes transparent or pale white. Tissue predominantly comprised of primary and secondary spematocytes. Few quantities of spermatids in lobules. |
| Ripening | White testes. Tissue consists predominantly of spermatocytes, spermatids and spermatozoa. Spermatozoa present in lobules, but none in spermatic ducts. |
| Spawning | White testes, enlarged. Mature spermatozoa fill the spermatic ducts. |
| Spent | Testes dull brown in colour. Developed lobules containing few remaining sperm. |
| Resting | Flat, white-grayish testes. Spermatogonia in the first spermatogenesis stage. |
|  |  |

## Statistical analysis

The Mann-Whitney test was used to determine possible sexual dimorphism based on data on standard length and body height for females and males. A $\chi^{2}$ goodness-of-fit test was performed to compare female to male ( $\mathrm{F}: \mathrm{M}$ ) ratios (per month and within size groups), with a hypothesized sex-ratio of 1:1. Differences in size at maturity and size between sexes within length classes were performed using the Mann-Whitney test.

The Kruskal-Wallis test was used to determine differences in gonadosomatic indices among months. Batch fecundity was calculated using the following equation:
$\mathrm{BF}=\mathrm{nWg} / \mathrm{w}$, in which: $\mathrm{BF}=$ batch fecundity, $\mathrm{n}=$ number of hydrated oocytes in the sample, $\mathrm{Wg}=$ the gonad weight and $\mathrm{w}=$ the sample weight. The number of batches was calculated based on the method proposed by Hunter and Macewicz (1985b). The significance level for all analyses was set at $\mathrm{P}<0.05$. The BioEstat 3.0 software program (Instituto de Desenvolvimento Sustentável Mamirauá - Amazonas) was used for these analyses.

## Results

## Sex ratio and size composition

The French angelfish, Pomacanthus paru, is a gonochoristic fish. Differences between sexes were found in total length $(Z(U)=3.1200, P=0.0018)$, standard length $(\mathrm{Z}(\mathrm{U})=4.2672, \mathrm{P}=0.0000)$, body height $(\mathrm{Z}(\mathrm{U})=2.96, \mathrm{P}=0.0030)$. Among 236 individuals sexed, 139 were female ( $58.89 \%$ ), 86 were male ( $36.44 \%$ ) and 11 were undefined (4.66\%) (Fig.2). Sex ratios were biased toward females in all bimesters, except September-October. Bimonthly sex ratios were statistically significant only in March-Apr/06 ( $\chi^{2}=6.48, \mathrm{P}=0.01$ ) and January-February/07 $\left(\chi^{2}=5.12, \mathrm{P}=0.02\right)$, where females were 3.63 -fold and 3.25 -fold, more abundant than males (Fig. 3). Differences in sex ratios for size classes were recorded only among these length classes $[15-30 \mathrm{~cm}(Z$ $(\mathrm{U})=4.19, \mathrm{P}=0.0000) ; 30-45 \mathrm{~cm}(\mathrm{Z}(\mathrm{U})=4.8131, \mathrm{P}=0.0000)$ (Fig. 4).


Figure 2: Size distribution between sexes of sampled individuals with bars indicating standard error.


Figure 3: Sampled individuals distribution of female and male of Pomacanthus paru among bimesters.


Figure 4: Mean total length distribution of Pomacanthus paru.

## Spawning season and gonadal development

Monthly changes in mean GSI for males and females are presented in Fig. 5 and were not statistically significant for males ( $\mathrm{K}-\mathrm{W}$ test male $\mathrm{H}=4.6852 \mathrm{P}=0.4555$ ), but significant for females in bimesters Mar-Apr and Nov-Dec (K-W test female H = $13.4832 \mathrm{P}<0.05$ ). The analysis of GSI for females indicates an increase beginning in January-February, with a peak in March-April, and gradual decline until August. GSI attained high levels in September-October, but declined in November-December and then began to rise. For males, the GSI is the highest in March-Apr, as observed in females. The GSI then declined abruptly and continued nearly the same until March.

The immature females occurred from April to January, but the highest frequency was found between July-August and September-October. Maturing and ripening stages occurred throughout the year, except in June, September, October and December for the maturing stage. The spawning stage was dominant in September-October and from January until April. In this period, the GSI increased, mainly between January and April
and in October. Resting ovaries were recorded throughout the year, with the exception of July, September and February. However, the spawning stage was recorded in these months (Fig. 6).

Males in immature stages were only recorded in a few months. The maturing stage was not observed in April, December or February, but spawning and spent stages were recorded. The ripening stage was more frequent in July-August and NovemberDecember. From May until October, the spawning stage was dominant. Individuals in the spent stage were recorded throughout the year. Resting testes were not recorded only in March-April and September-October (Fig. 6).


Figure 5: Bimonthly changes of the mean gonadosomatic index (GSI) in female and male Pomacanthus paru with bars and values indicating the standard error and the number of individuals analyzed for each stage, respectively.


Figure 6: Bimonthly percentage frequencies of occurrence of gonadal developmental stages in female and male Pomacanthus paru. The values inform the number individual analyzed for each stage.

## Size at maturity

Individuals fit for reproduction appeared at 20 to 25 cm for females and 25 to 30 cm TL for males. The L50 were different between sexes, being maturity reached at
female and male were 23.18 cm TL and 25.24 cm TL, respectively (Fig. 7).

Female


Figure 7: Percentage of individuals in spawning and immature stage versus length class and mean gonad weight for female and male (A) and graphic showing the $\mathrm{L}_{50}$ for female and male of Pomacanthus paru (B).

## Fecundity

Table 2 displays estimates of the minimum, maximum and mean values for the batch and relative fecundities. Hydrating oocytes ranged in size from 350 to $800 \mu \mathrm{~m}$.

Table 2: Minimum, maximum and mean values of batch (BF), total (TF) and relative (RF) fecundities of Pomacanthus paru.

|  | TL* $(\mathrm{cm})$ | $\mathrm{BW}^{*}(\mathrm{~g})$ | BF | RF |
| :--- | :---: | :---: | :---: | :---: |
| Minimum value | 23.18 | 428 | 109.6 | 4.73 |
| Maximum value | 34.24 | 1354 | 29475 | 860.83 |
| Mean value $\pm$ SE |  |  | $3.751 .62 \pm 1.396 .78$ | $118.48 \pm 41.42$ |
| *TL $=$ total length, BW $=$ body weigth |  |  |  |  |

## Discussion

## Sex ratio and size composition

In the present study, Pomacanthus paru was classified as a gonochoric species. An overlap in size distributions, similar mean sizes of adult males and females and the lack of histological evidence for hermaphroditism support this sexual pattern. Hermaphroditism is a common process in tropical fish families and is recorded in, at least, eighteen families (Ross, 1990). In the family Pomacanthidae, protogynous hermaphoditism has been found in three genera: Centropyge (Moyer and Nazakono, 1978; Bruce, 1980), Geniacanthus (Bruce, 1980) and Holacanthus (Hourigan and Kelley, 1985, Nottingham et al., 2003). However, it has been suggested that Pomacanthus species are gonochoristic (Michael, 2004). In most gonochoric fish, size
distributions of females and males overlap broadly. However, the population structure alone is not a reliable indicator of sexual pattern, as bimodal size may be observed in gonochoric species that possess size dimorphism (Sadovy, 1986) or differential rates of growth, maturation, or mortality by sex (Sadovy and Shapiro, 1987).

Species that occur in pairs are commonly gonochoric, as was observed for Pomacanthus paru in the present study. However, the gonochoric pattern also occurs in fishes with group-spawning mating systems, where all males have access to females, and sperm competition is intense (Warner, 1982). The mating system of the genus Pomacanthus depends on the population density in a given location. In some areas, $P$. paru form stable pairs, whereas in locations in which the species is abundant this fish forms harems (Michael, 2004). However, some authors state that Pomacanthus paru is consistently found in pairs, regardless of whether the species is abundant or not (Moyer et al., 1983). Despite the common occurrence of pairs, spawning involves pairs and solitary individuals, as observed by Thresher (1980) and Moyer et al. (1983).

Sexual dimorphism is uncommon among marine teleost fish. It can be manifested as changes in body shape during growth, which is related to protogynous hermaphroditism. However, in gonochoristic species, size differences between sexes have also been recorded (García-Cagide et al., 2001), as was observed for Pomacanthus paru. Sexual size dimorphism is a ubiquitous characteristic of angelfish, for which males are generally larger than females. Size dimorphism and sexual dichromatism have been recorded in some species of the genus Pomacanthus (Thresher, 1982). Feitosa et al. (unpublished data - chapter 2) observed a different pattern of growth between sexes, in which males continued to grow, while females already reached the asymptotic length. Reinforcing the size dimorphism for Pomacanthus, Moyer et al. (1983) stated that
sexual size dimorphism is not conspicuous in most adult pairs of $P$. paru, however after a close examination, a slight size difference between paired individuals can be noticed.

Sex ratio is a population characteristic that plays an important role in reproduction. In species of snappers, jacks and grunts, females are more abundant in almost all length classes and reach a larger size than males (García-Cagide et al., 2001). In these cases, female dominance may be explained by a greater survivorship, but also by differences in habitat preference (García-Cagide et al., 2001). According to AburtoOropeza et al. (2000), the sex ratio of angelfish populations (proportion of sexes and sizes) seems to be determined by the mating system. In the family Pomacanthidae, there are different reproductive styles among genera (Allen, 1979) and most are protogynous hermaphrodite (Thresher, 1984). Few studies, however, have addressed the role of other factors, such as food availability, in the structuring of angelfish communities (ArellanoMartínez et al., 1999; Aburto-Oropeza et al., 2000).

Aburto-Oropeza et al. (2000) observed differences in habitat preference between sexes in the angelfish Holacanthus passer, for which a significant habitat overlap was only recorded between large females and small males. For this angelfish, sex differed significantly over the size range, with females prevailing at smaller lengths and males at larger lengths (Arellano-Martínez et al., 1999). It may be suggested that there is a habitat preference between sexes in Pomacanthus paru, as a similar pattern to that described by Arellano-Martínez et al. (1999) was recorded in the samples of the present study. In a study performed in Caribbean waters, Aiken (1983) found that the sex ratios of the various species of chaetodonthids and pomacanthids caught in traps were female biased, mainly in Pomacanthus arcuatus (M:F - 1:2.51) and Pomacanthus paru (M:F 1:3.28). The author attributes these variations to differences in sample site depths.

Other explanations for this pattern are that females enter fish traps more readily than males (Gaut and Munro, 1983) or that females fit for reproduction move into the sampling area and are more susceptible to traps, due to their reproductive status. Females are especially more abundant in samples in months related to the spawning peak. As smaller individuals between 0 and 15 cm TL (length class dominated by males) were not caught by traps, the female dominance of $P$. paru may be explained by these factors.

## Spawning season and gonadal development

Although female of Pomacanthus paru has two reproductive peaks and male one, the species is probably capable of spawning throughout the year, based on the occurrence of females in the spawning stage and males in the spent stage in nearly every month. In Caribbean waters, ripe individuals of $P$. paru have been collected in May, July, August, October and November and from January to August, with a maximal proportion in April for Holacanthus ciliaris (Munro et al., 1973). For Pomacanthus arcuatus, the greatest proportions of ripe fishes were collected in October and January, but according to Munro et al. (1973), there is no discernible seasonal trend in the data. Ripe individuals of Holacanthus tricolor were found in all months, with the exception of December for which there is no data. According to Moyer et al. (1983), H. tricolor spawns most of the year in Puerto Rico. Arellano-Martínez and Ceballos-Vásquez (2001) also collected ripe fishes of Holacanthus passer in April. Although ripe P. paru were collected in every month in the present study, the data presented are in agreement with those obtained by Munro et al. (1973), Moyer et al. (1983) and Arellano-Martinez et al. (2001) with regard to spawning months.

The gonadosomatic index value is an indicator of the duration of the reproductive season, but caution should be exercised in its interpretation due to regional and temporal variations (Jons and Miranda, 1997). In fact, seasonal variations in GSI must be analyzed together with other factors, such as the monthly proportion of fish in different stages of gonad development (García-Cagide et al., 2001). In the present study, the GSI index demonstrated a unique and common peak (March - April) for both sexes. Two peaks were recorded for females, - a strong peak in January-February and MarchApril and a weak one in September-October. A high frequency of males in spawning stages was recorded in May until October, when the GSI index values were low. In Hyporhamphus australis, some gonads have been found in spawning condition outside their respective GSI-defined peak spawning periods (Hughes and Stewart, 2006). For two species of tropical Atlantic hemiramphids it has been demonstrated that, while the spawning of young females is strongly seasonal, older female fish spawn throughout the year (McBride and Thurman, 2003). Moyer et al. (1983) found a daily spawning cycle that occurs throughout all or most of the lunar cycle in six American species and fifteen Western Pacific species of angelfishes. Many tropical fish are intermittent spawners and, for such individuals, the GSI provides information for only a certain period of the reproductive cycle, rather than entire year (García-Cagide et al., 2001). Despite the values of this index, the data of the present study support a pattern of reproductive activity throughout the year, with two spawning peaks.

## Size at maturity

Size at maturity is influenced by environmental and genetic factors (Wooton, 1979), but fishing pressure can also affect this parameter (Jennings et al., 2001). Based on GSI index of Holacanthus passer, Arellano-Martinez and Ceballos-Vásquez (2001) affirm that due to the gonad size, male fish requires less stored energy for gonadal
development and it may start to mature earlier than females. However, the results of the present study demonstrated that $P$. paru females mature earlier than males. Spawning stage first appeared in females at 23 cm TL and in males at 25 cm TL. Besides, the $\mathrm{L}_{50}$ for females was 5 cm smaller than males. The total length of the smallest mature Pomacanthus paru female caught in Caribbean waters by Aiken (1983) was 23 cm . The author suggests that males tend to mature at a larger size than females, as no male was captured. The results of the present study corroborate with Aiken (1983).

## Fecundity

According to Hunter and Goldberg (1980), the number of hydrated eggs in ovaries prior to ovulation should give the most accurate estimate of fecundity and this method has been used on several Engraulius species (Hunter and Goldberg, 1980; Hunter et al., 1984; Hunter and Macewicz, 1985a), as well as on the chub mackerel (Scomber japonicus) (Peña et al., 1986) and dwarf herring (García-Cagide et al., 2001). The fecundity obtained in the present study was much lower than that described by Aiken (1983), who found a mean value of 34200 . This difference may be due to the sample size, as Aiken (1983) only analyzed two individuals, whereas 44 females were analyzed in the present study. Among this total, one fish had values similar (29475) to that determined by Aiken (1983). It may be suggested that the sample size used by Hourigan and Kelley (1985) was insufficient for a comparative analysis. The authors only sampled ten Holacanthus tricolor females, - five in May and five in September. The authors recorded a higher number of hydrated oocytes: $15330 \pm 5490$ in May and $35840 \pm 18480$ in September. Similarities were recorded between the present study and that performed by Arellano - Martínez et al. (2006) for Pomacanthus zonipectus, in which these authors found a mean values of $79.4 \pm 9.2$ for relative fecundity. The range
size of hydrating oocytes found in the present study corroborates the results obtained by Hourigan and Kelley (1985) for Holacanthus tricolor (363-721 $\mu \mathrm{m}$ ) and by ArellanoMartínez et al. (2006) for Pomacanthus zonipectus $(675 \pm 1.2 \mu \mathrm{~m})$.

Besides the sample size issues, the definition of spawning stage without determinate the minimal quantity of these oocytes for this stage should be revised. This definition, based on the simple presence of hydrated oocytes, may be influencing the higher variation recorded in the present results of fecundity.

## Considerations

The present study provides important information on the reproductive biology of P. paru. The French angelfish is a gonochoristic species. Some hypotheses, such as habitat preference between sexes, greater female susceptibility to trap fisheries and female migration to sampling areas, may explain the role of population sex structure of Pomacanthus paru. However, further studies are needed to clear up this issue. This species is mainly targeted by the aquarium trade. Species-based quotas have been established by the Brazilian environmental protection agency (IBAMA) to ensure that harvests are maintained at a sustainable level. Despite the determination of the size at maturity in the present study, this information is not relevant for the aquarium trade management, as most commercialized ornamental fish are juveniles under 10 cm in standard length. It can be suggested that conservationist issues should be based on quantitative data (capture) per area and the establishment of protected areas.

Pomacanthus paru is also commonly caught as bycatch in trap fishery, an unregulated multi-specific activity. Specimens captured as bycatch are not landed and are usually returned to the sea (many still alive, according to the fishermen). The survival of these individuals is doubtful, as the traps are hauled quickly to surface and problems related to decompression have often been reported. Little is known regarding
the impact of this activity, being difficult to manage it. Monitoring and management of this fishery, a growing activity with catches exported to the international market, is mandatory in order to assess the impact of this kind of fishery on both target and nontarget species.

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## References

Aburto-Oropeza, O.; Sala, E. and Sánchez-Ortiz, C. 2000. Feeding behavior, habitat use, and abundance of the Angelfish Holacanthus passer (Pomacanthidae) in the Southern Sea of Cortés. Environmental Biology of Fishes, 57: 435-442.

Aiken, K. 1983. The biology, ecology and bionomics of the butterfly and angelfishes, Chaetodontidae. pp. 155 - 165. In: Caribbean coral reef fisheries resource. Ed by J. L. Munro. Iclarm studies and reviews 7, Manila, Philippines, 283pp.

Aldenhoven, J. M. 1986. Different reproductive behavior strategies in sex changing coral reef fish Centropyge bicolor (Pomacanthidae). Australian Journal of Marine and Freshwater Research, 37: 353-360.

Allen, G.R. 1979. Butterfly and angelfishes of the world, vol. 2. Mergus, Melle. 352 pp. Allen, G.R.; Steene, R. and Allen, M. 1998. Introducing angelfishes. pp. 8 - 12. In: A guide to angelfishes and butterflyfishes. Odyssey Publishing: USA/ Tropical Reef Research: Australia, 250pp.

Araújo, M. E. and Albuquerque Filho, A. C. 2005. Biologia das principais espécies de peixes ornamentais marinhos do Brasil: uma revisão bibliográfica e documental. Boletim Técnico Científico do CEPENE, 13: 109-154.

Arellano-Martínez, M., Ceballos-Vásquez, B. P., Garcia-Dominquez, F. and GalvánMagaña, F. 1999. Reproductive biology of the King Angelfish Holacanthus passer Valenciennes 1846 in the Gulf of California, Mexico. Bulletin of Marine Science, 65: 677-685.

Arellano-Martínez, M. and Ceballos-Vásquez, B. P. 2001. Reproductive activity and condition index of Holacanthus passer (Teleostei: Pomacanthidae) in the Gulf of California, Mexico. Revista de Biologia Tropical, 49: 939 - 943.

Arellano-Martínez, M., Ceballos-Vásquez, B. P., Olalde, L. H. and Galván-Magaña, F. 2006. Fecundidad del Ángel de Cortéz Pomacanthus zonipectus (Teleostei: Pomacanthidae) em la isla Espíritu Santo, Golfo de Califórnia, Mexico. Ciencias Marinas, 32: 65-71.

Bauer, J. A. and Bauer, S. E. 1981. Reproductive biology of pigmy angelfishes of the genus Centropyge (Pomacanthidae). Bulletin of Marine Science, 31: 495-513.

Bruce, R. W. 1980. Protogynous hermaphroditism in two marine angelfishes. Copeia, 1980: 353-355.

Cervigón, F. 1993. Pomacanthidae. pp. 339 - 346. In: Los Peces Marinos de Venezuela. Fundación Científica Los Roques, Caracas, 951pp. Feitosa, C. V., Ferreira, B. P. and Araújo, M. E. 2008. A rapid new method for assessing sustainability of ornamental fish by-catch from coral reefs. Marine and Freshwater Research, 59: 1092-1100.

Feitoza, B. M., Rocha, L. A., Luiz-Júnior, O. J., Floeter, S. R. and Gasparini, J. L. 2003. Reef fishes of St. Paul's Rocks: new records and notes on biology and zoogeography. Aqua, Journal of Ichthyology and Aquatic Biology. 7:61-82.

García-Cagide, A., R. Claro, and B. V. Koshelev. 2001. Reproductive patterns of f ishes of the Cuban shelf. In: Ecology of the marine fishes of Cuba. pp.73-114. Ed by R. Claro, K. C. Lindeman and L. R. Parenti. Smithsonian Institution Press, Washington, DC, 253pp.

Gaut, V. C. and Munro, J. L. 1983. The biology, ecology and bionomics of the grunts, Pomadasydae. pp. 110 - 141. In: Caribbean coral reef fisheries resource. Ed by J. L. Munro. Iclarm studies and reviews 7, Manila, Philippines, 283pp.

Hourigan, T. F. and Kelley, C. D. 1985. Histology of the gonads and observations on the social behavior of the Caribbean angelfish Holacanthus tricolor. Marine Biology, 88: 311-322.

Hughes, J. M. and Stewart, J. 2006. Reproductive biology of three commercially important Hemiramphid species in south-eastern Australia. Environmental Biology of Fishes, 75: 237-256.

Hunter, J. R. and Goldberg, S. R. 1980. Spawning incidence and batch fecundity in northern anchovy, Engraulius mordax. Fishery bulletin, 77: 641-652.

Hunter, J. R., Lo, N. H. and Leong, R. 1984. Batch fecundity in multiple spawning fishes. In: An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, Engraulius mordax. pp. $67-77$. Edited by R. Lasker. U.S. Department of Commerce, NOAA Technical Report NMFS 36.

Hunter, J. R. and Macewicz, B. J. 1985a. Measurement of spawning frequency in multiple spawning fishes. In: An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, Engraulius mordax. pp. 79

- 94. Edited by R. Lasker. U.S. Department of Commerce, NOAA Technical Report NMFS 36.

Hunter, J. R. and Macewicz, B. J. 1985b. Rates of atresia in the ovary of captive and wild northern anchovy, Engraulius mordax. Fishery Bulletin, 83: 119-136.

Jennings, S.; Kaiser, M. J.; Reynolds, J. D. 2001. Fishing effects on populations and communities. pp. 239 - 257. In: Marine Fisheries Ecology. Blackwell Science, London, 417pp.

Jons, G. D. and Miranda, L. E. 1997. Ovarian weight as an index of fecundity, maturity and spawning periodicity. Journal of Fish Biology, 50: 150-156.

Maugé, L. A. 1990 Pomacanthidae. p. 841. In: Ed by Quero, J.C., Hureau, J.C., Karrer, C., Post, A. and Saldanha, L. Check-list of the fishes of the eastern tropical Atlantic (CLOFETA). JNICT, Lisbon, SEI, Paris; and UNESCO, Paris. Vol. 2.

McBride, R. S. and Thurman, P. E. 2003. Reproductive biology of Hemiramphus brasiliensis and H. balao (Hemiramphidae): maturation, spawning frequency, and fecundity. Biological Bulletin, 204: 57-67.

Menezes, N. A., Buckup, P. A., Figueiredo, J. L. and Moura, R. L. 2003. Catálogo das espécies de peixes marinhos do Brasil. Museu de Zoologia USP, São Paulo.

Michael, S. W. 2004. Family Pomacanthidae/Angelfishes. pp. 296 - 323 In: Angelfishes \& Butterflyfishes. T.F.H. Publications, New Jersey, 344pp.

Monteiro Neto, C., Cunha, F. E. A., Nottingham, M. C, Araújo, M. E, Rosa, I. L. and Barros, G. M. L. 2003. Analysis of the marine ornamental fish trade at Ceará State, northeast Brazil. Biodiversity and Conservation, 12: 1287-1295. Moyer, J. T. and Nazakomo, A. 1978. Population structure, reproductive behavior, and protogynous hermafroditism in the angelfish Centropyge interruptus at Miyake-jimi, Japan. Japan Journal of Ichthyology, 25: 25-39.

Moyer, J. T.; Thresher, R. E. and Colin, P. L., 1983. Courtship, spawning and inferred social organization of American angelfishes (Genera Pomacanthus, Holacanthus and Centropyge; Pomacanthidae). Environmental Biology of Fishes, 9: 25-39.

Munro, J.L., Gaut,V.C., Thompson, R. and Reeson, P.H.. 1973. The spawning seasons of Caribbean reef fishes. Journal of Fish Biology, 5: 69-84.

Murphy, M. D. and Taylor, R. G. 1990. Reproduction, growth and mortality of red drum Sciaenops ocellatus in Florida waters. Fishery bulletin, 88: 531-542.

Nottingham, M. C.; Cunha, F. E. and Monteiro Neto, C. 2000. Captura de peixes ornamentais marinhos no Ceará. Arquivos Ciências do Mar, 33: 113 - 118 .

Nottingham, M.C.; Silva, J.R.F. and Araújo, M.E. 2003. Morphology and histology of the testicles of Queen Angelfish Holacanthus ciliaris (Perciformes: Pomacnthidae). Arquivos Ciências do Mar, 36: 89-94.

Peña, N.; Alheit, I.; Nakama, M. E. 1996. Fecundidad parcial de la caballa del Perú (Scomber japonicus peruanus). Boletin del Instituto del Mar de Peru, 10: 93-104.

Randall, J. E. 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography Miami, 5: 665-847.

Ross, R.M. 1990. The evolution of sex-change mechanisms in fishes. Environmental Biology of Fishes, 29: 81-93.

Sadovy, Y. 1996. Reproduction in reef fishery species. pp. 15 - 60. In: Reef fisheries Edited by N. V. C. Polunin and C. M. Roberts. Chapman and Hall, London, 496pp. Sadovy, Y., Shapiro, D. Y. 1987. Criteria for the diagnosis of hermaphroditism in fishes. Copeia, 1987: 136-156

Sakai, Y. 1986. Fecundity of female angelfish, Centropyge ferrugatus, independent of body size: field collection of spawned eggs. Ichthyological Research, 43: 186-189.

Sakai, Y. and Kohda, M. 1997. Harem structure of the protogyneous angelfish, Centropyge ferrugatus (Pomacanthidae). Environmental Biology of Fishes, 49: 333339.

Thresher, R. E. 1980. Angelfish. pp. 37 - 46. In: Reef fish: behavior and ecology on the reef and in the aquarium. The Palmetto Publishing Company, St. Petresburg, 171pp. Tresher, R. E. 1982. Courtship and spawning in the emperor angelfish Pomacanthus imperator, with comments on reproduction in other pomacanthid fishes. Marine Biology, 70: 149-156.

Thresher, R. E. 1984. Angelfishes. pp. 244 - 261. In: Reproduction in reef fishes. TFH Publications, New Jersey, 398pp.

Vazzoler, A. E. A. M. 1996. Fecundidade: Parte prática. pp. 142 - 151. In: Biologia da reprodução de peixes teleósteos: Teoria e prática. EDUEM, Maringá, 169 pp.

Warner, R. R. 1982. Mating systems, sex change and sexual demography in the rainbow wrasse, Thalassoma lucasanum. Copeia, 1982: 653-661.

West, G. 1990. Methods for assessing ovarian development in fishes: a review. Australian Journal of Marine and Freshwater Research, 41: 199-222.

Wootton, R. J. 1979. Energy costs off egg production and environmental determinants of fecundity in teleost fishes. pp. 133-159. In: Fish phenology: Anabolic adaptiveness in teleosts. Edited by P. J. Miller. Academic Press, London, 449pp.

Yamaguchi, A.; Todoroki, T. and Kume, G. 2006. Reproductive cycle, sexual maturity and diel-reproductive periodicity of white croaker, Pennahia argentata (Sciaenidae), in Ariake Sound, Japan. Fisheries Research, 82: 95-100.

# Capítulo 2 - Idade e crescimento do Paru preto Pomacanthus paru (Teleostei: Pomacanthidae) no nordeste do Brasil. 

Chapter 2* - Age and growth of the French angelfish Pomacanthus paru (Teleostei: Pomacanthidae) in Northeastern Brazil.

* Capítulo em formato de artigo e padronizado de acordo com as normas da revista Journal of Fish Biology.


## Age and growth of the French angelfish Pomacanthus paru (Teleostei:

## Pomacanthidae) in Northeastern Brazil.

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#### Abstract

The aim of the present study was to describe age and growth of the French angelfish Pomacanthus paru. Age was determined by sectioned otoliths alone. All treated otoliths with tetracycline were one year of age and revealed a clear fluorescent mark when observed under UV light. Based on age determination studies, increments observed in sagittae otoliths of tropical fish may be consistently interpreted as having annual periodicity. Otolith weight increased exponentially with standard length and linearly with age. This indicates that otolith growth continues with age and is independent of size. Age of the fish in the sample ranged from 1 to 27 years, with males exhibiting lower K and greater asymptotic length than females. $P$. paru attains maximal size slowly and has a long lifespan. Most linear growth is achieved by approximately $52 \%$ of lifespan. Besides being an important ornamental species, P. paru has been commonly caught as bycatch in trap fisheries for decades. These growth parameters should be used with the purpose of managing fisheries targeting this species before more meaningful limits can be imposed. In the case of aquarium trade management, it can be suggested that conservationist issues should be based on capture per area and the establishment of protected areas.


Key words: Pomacanthus paru, growth parameters, validation, aquarium trade.
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## Introduction

One of the most commonly employed methods for age determination is the interpretation of rhythmic deposition in calcified tissues used as time markers (Casselman, 1987). Considered the most appropriate structure for age determination (Six \& Horton, 1977), otoliths are calcium carbonate concretions in aragonite crystal form (Degens et al., 1969) and are found in the membranous labyrinth of the inner ear of teleost fish (Lowestein, 1971). The use of otoliths for age determination was first developed for temperate fish populations (Brothers, 1980), which have seasonally controlled periods of growth and spawning. Due to the lack of seasonality in tropical waters, the use of the otolith method for age studies on tropical fish began as a complex process. However, in the late 1980s, Longhurst \& Pauly (1987) stated that the growth of tropical fish follows expected seasonal patterns, which can be observed using length frequency data or the analysis of seasonal bands in otoliths.

Despite the importance of studies on age, growth, mortality and longevity, limited information is available on the population dynamics of tropical fish (Radtke, 1987). Age and growth studies are crucial to understanding the life history traits of fish species, including population structure, changes in population growth due to environmental variations and recruitment success (Dee \& Radtke, 1989; Zekeria et al., 2000). Such studies are required to explain demographic characteristics that are unique to tropical fish populations and determine environmental influences on life history events (Radtke, 1987). Furthermore, growth and ageing studies on species undergoing fishery pressure provides indispensable information for stock assessments and fishery management (Aliaume et al., 2000).

Information on growth of coral reef fish is limited to a few families, such as acanthurids, haemulids, lutjanids, scarids, serranids, sparids (Choat \& Axe, 1996; Choat
et al., 1996). For the family Pomacanthidae, estimates from age-at-length data are only available for one species - Pomacanthus imperator (Bloch, 1787) (Chung \& Woo, 1999). Moreover, the method employed for ageing this species was the reading of scales, which is prone to error (Williams \& Bedford, 1974; Erickson, 1983).

Fish from the family Pomacanthidae are among the most colorful and recognizable groups of reef fish (Thresher, 1982). This family comprises 88 species, consisting of eight genera and represents one of the most noticeable components in reef fish assemblages, with representatives in all tropical seas (Allen et al., 1998). Although angelfish are analogous in overall appearance, there is a diverse range of ecological traits within the family, such as differences in body size, color pattern, reproductive system and diet (Bellwood et al., 2004).

The French angelfish Pomacanthus paru (Bloch, 1787) occurs from Florida, the Bahamas and the northern Gulf of Mexico down to Brazil (Menezes et al., 2003). It is also recorded for St. Peter and St. Paul's Rocks (Feitoza et al., 2003) and Ascension Island (Maugé, 1990) in the Central Atlantic and the Gulf of Guinea. Maximal length reported for this species is 41 cm (Cervigón, 1993). It is distributed in waters from 5 to 100 m , with juveniles and subadults being more frequent in shallow waters. This species is an omnivore and sponges are its main food item (Randall, 1967). It is a gonochoric species (Feitosa et al., unpublished data) and it seems that adults generally form stable pairs, although in areas where the fish is more abundant, it is known to form small harems (Thresher, 1984; Michael, 2004).

Pomacanthid species are among the most harvested for the Brazilian aquarium trade and P. paru is one of the most exported species (Nottingham et al., 2000; Araújo \& Albuquerque-Filho, 2005; Monteiro-Neto et al., 2003). Along with the fishing pressure by the Brazilian aquarium trade, this species is also caught as bycatch (Feitosa
et al., 2008). Management measures for this species are restricted to a Federal Act (56/04) established in 2004 with the purpose of managing the aquarium trade through the establishment of export quotas.

In the present study, age and growth of $P$. paru were studied through the validation and examination of annual marks in sagittae otoliths.

## Materials and methods

Sampling design
The fish were sampled from commercial boats from the Itamaracá Island Fishing Colony, located on Pilar beach ( $7^{\circ} 45^{\prime} 17.80^{\prime}$ 'S $-34^{\circ} 49^{\prime} 26.46^{\prime}$ 'W) (Itamaracá, state of Pernambuco, Brazil - Fig. 1). These fish were caught as bycatch during trap fishery activities targeting the spotted goatfish, Pseudupeneus maculatus (Bloch, 1793), and parrotfish, Sparisoma spp. In this fishery, traps are deployed unbaited next to reefs and hauled 6 hours later. Occasionally, depending on factors such as wind and currents, some traps are left for longer periods and only hauled after 48 hours. Sampling was performed weekly from March 2006 to February 2007. As individuals smaller than 15 cm are not captured in this type of fishery, such individuals were bought from fish collectors between September 2006 and February 2007.


Figure 1: Location of sampled site.
Otolith ageing
Fish were measured for total length [TL (cm)] and standard length [SL (cm)], weighed (g) and sexed. The largest otoliths (sagittae) were removed for analysis and stored dry. Whenever possible, the left otolith was used for both whole and sectioned views. Rings were counted for whole otoliths by immersing the otoliths concave side up on a watch glass with a blackened bottom containing $100 \%$ ethanol and viewed through a binocular dissecting microscope. Opaque bands were counted on the distal surface from the nucleus to the dorsal side. Prior to sectioning, all pairs were measured and weighed to the nearest 0.01 g .

The otoliths were embedded in an epoxy resin prior to reading. Each otolith was sectioned transversely (approximately 0.3 mm thick) with a low-speed saw. Sections were mounted on microscope slides with Histomount mounting media and examined for opaque bands under a dissecting microscope using reflected light.

To assess the precision of the readings, two independent readers counted age marks on whole and sectioned otoliths with no knowledge of fish size. A second reader tested the precision of the first reader for a subsample of 50 otoliths sections ( $21 \%$ ). With these results, the index of average percentage error (IAPE) between readers was calculated (Beamish \& Fournier, 1981). If the readers diverged by more than $10 \%$ for a given otolith section, the readings were repeated. The data were included in the analysis only when the IAPE was below $10 \%$.

A validation experiment was performed to determine the accuracy of the otolith readings. For this test 6 individuals were used. As individuals sampled for this test were smaller than 6 cm , the specimens were marked by immersion in a solution of tetracycline and seawater (Beamish \& McFarlane, 1987), with an initial concentration of $100 \mathrm{mg} \mathrm{l}^{-1}$. Each subsequent four hours, the same concentration ( $100 \mathrm{mg} \mathrm{l}^{-1} / \mathrm{h}$ ) was added to the solution until reaching the maximal concentration of $500 \mathrm{mg} \mathrm{l}^{-1}$. The fish were kept in this solution for 12 hours (Hernaman et al., 2000). After this procedure, they remained in aquarium for 1 year, with a mean salinity and temperature of $30 \%_{0}$ and $28^{\circ} \mathrm{C}$, respectively.

The treated otoliths were sectioned in the same way as the unlabeled ones and analyzed under a microscope with an ultraviolet light source to detect the fluorescent mark. An external fiber-optic light was coupled to the microscope in order to observe the opaque bands and fluorescent marks simultaneously (Ferreira \& Russ, 1992).

Growth was investigated by fitting the von Bertalanffy (1938) growth function to size-at-age data using the nonlinear optimization method on the Kaleidagraph 4.0 software program. The model was fit for each sex separately. The growth function is defined as follows:

$$
L t=L \infty\left(1-e^{-k(t-t 0)}\right)
$$

in which Lt is length at time $\mathrm{t}, \mathrm{L} \infty$ is asymptotic length, k is the growth coefficient and $\mathrm{t}_{0}$ is the hypothetical time at which length is equal zero. The rate of increase in size with age between sexes was compared using the Mann-Whitney test ( $\alpha=0.05$ ). The paired $t-$ test was used to compare the weight of left and right sagittae otolith ( $\alpha=0.05$ ). The relationship between otolith weight, standard length and age was determined through simple linear regression analysis.

Parameters of the length-weight relationship were obtained by fitting the function $\mathrm{W}=\mathrm{aL}_{\mathrm{s}}{ }^{\mathrm{b}}$ to length and weight data, in which W is the total weight, $a$ is the constant (determined empirically), $\mathrm{L}_{\mathrm{s}}$ is the standard length and b is close to 3 for species with isometric growth.

## Results

In French angelfish, the sagittae otolith is the largest and oval shaped, with a pointed rostrum. It is laterally compressed, with a heterosucoid sulcus acusticus (Fig. 2). A pattern of opaque and translucent bands can be recognized and counted on whole and sectioned otoliths. Nevertheless, counting opaque bands on whole otoliths is a complex task due to the overlapping of bands at the margins in larger fish and regular divergence in counts between different otolith regions, mainly in the dorsal area. Due to these complexities, the age of $P$. paru was determined only on sectioned otoliths (Fig. 2).


Fig. 2: Whole (A) and sectioned (B) sagittae otoliths of a 8 and a 11 years old Pomacanthus paru $(\mathrm{a}=$ anterior, $\mathrm{p}=$ posterior, $\mathrm{d}=$ dorsal, $\mathrm{v}=$ ventral, $\mathrm{di}=$ distal, $\mathrm{pr}=$ proximal).

The sections of all treated otoliths revealed an opaque band between a clear fluorescent mark and the edge when observed under an external light source and UV light (Fig 3). Observations from all of the sections support the hypothesis that the annulus is formed once a year. All the treated French angelfish were one year old.


Fig. 3: Sectioned otolith treated with tetracycline observed under UV light (A) and under an external light source and UV light (B). TM - tetracycline mark, OM - opaque mark.

Otoliths ranged in weight from $0.002(7.81 \mathrm{~cm}, 16 \mathrm{~g}, 4$-year-old fish) to 0.169 g ( $38.64 \mathrm{~cm}, 1.396 \mathrm{~g}, 26$-year-old fish). There was no significant difference between the weight of the left and right otolith (paired t -test, $\mathrm{n}=153, \mathrm{P}>0.05$ ). The exponential relationship between otolith weight and standard length follows the equation $\mathrm{OW}=$ $0.0049 \mathrm{e}^{0.1082 \mathrm{SL}}(\mathrm{r}=0.89, \mathrm{n}=184)$, in which OW is otolith weight $(\mathrm{g})$ and SL is standard length (cm) (Fig. 4). Otolith weight increased linearly with age and was described by the equation OW $=0.0053 \mathrm{SL}+0.0036(\mathrm{r}=0.64, \mathrm{n}=167)($ Fig. 5). The relationship of total weight to standard length is $\mathrm{W}=0.1192 \mathrm{SL}^{2.794}(\mathrm{r}=0.98, \mathrm{n}=236)($ Fig. 6).


Figure 4: Relation between sagittae otolith weight and standard length for Pomacanthus
paru. $\mathrm{SL}=$ standard length $(\mathrm{cm}), \mathrm{OW}=$ otolith weight


Figure 5: Relation between otolith weight and age for Pomacanthus paru. $\mathrm{A}=$ age years, $\mathrm{OW}=$ otolith weight.


Figure 6: Relation of weight to length for Pomacanthus paru. SL $=$ standard length $(\mathrm{cm}), \mathrm{W}=$ total weight $(\mathrm{g})$.

Age of the specimens in the sample ranged from 1 to 27 years (Fig. 7). Females age range was 2 to 27 years and males was 1 to 26 . Statistically differences were recorded for size at age between sexes only for the age ranging from 16 to $20(\mathrm{n}=27)$ and 21 to 27 years $(\mathrm{n}=15)$ (Mann-Whitney test, $\mathrm{P}<0.05)$. A total of $2.30 \%$ of the otolith sections were unreadable and were not included in the analysis. The average percentage error between readers was low ( $9.80 \%$ ). French angelfish are long-lived (to $>27$ years) and attain maximal size slowly, especially males. The plots were fitted best by the von Bertalanffy growth function for females: $\mathrm{Lt}=26.66\left(1-\mathrm{e}^{-0.18(t+0.56)}\right)$ and males $L t=44.11\left(1-\mathrm{e}^{-0.05(\mathrm{t}+3.34)}\right)$.


Figure 7: Von Bertalanffy growth curve fitted to length at age data of female and male of Pomacanthus paru.

## Discussion

Despite being widely recognized as important coral reef inhabitants and very significant in marine aquarium trade, there are few studies on age and growth of representatives of the family Pomacanthidae (Chung \& Woo, 1999). This may be attributed to the difficulty in sampling individuals in all length classes.

In the present study, sagittae otoliths - which are commonly the largest (Panella, 1971) - from French angelfish exhibited a regular pattern of annual opaque and translucent bands, the readings of which were highly repeatable, with an average error of $9.80 \%$. Based on age determination studies, increments observed in the sectioned sagittae otoliths of tropical fish may be reliably interpreted as having annual periodicity (Choat \& Robertson, 2002).

The relationship between otolith weight and age was linear. This suggests that otolith growth is continuous for $P$. paru, while fish size (standard length) is asymptotic
at intermediate ages, indicating that this relationship is not continuous. Thus, otolith growth is continuous with age and is independent of fish size. It seems that this is a general rule of fish growth, as this pattern has been observed in several other species (Dee \& Radtke, 1989; Hart \& Russ, 1996; Schwamborn \& Ferreira, 2000; Amezcua et al., 2006; Araújo \& Martins, 2006; Zekeria et al., 2006). Bands were deposited annually and the weight of otoliths increased throughout the lifespan, thereby fulfilling the fundamental criteria required for ageing (Fowler \& Doherty, 1992).

Growth data for the French angelfish fitted the von Bertallanfy model well. Longevity was up to 27 years and maximal asymptotic standard length was 44.11 cm , with males exhibiting lower K and greater $\mathrm{L} \infty$. However, the longevity was nearly the same between sexes. Females reach asymptotic length nearly at age 15 and in this age males continue to grow attaining greater sizes at the subsequent ages. The samples used in the present study came from trap fisheries and, consequently, were related to the selectivity of this fishing gear. For the angelfish Holacanthus passer sex ratio differed significantly over the size range, with females prevailing at small lengths and males at larger lengths (Arellano-Martínez et al. 1999). A similar pattern was observed in the present study, in which males were larger than females. It is possible that when females attain age at sexual maturity, they strongly reduce their growth.

Reinforcing the differences in growth patterns between sexes, Feitosa et al. (unpublished data - chapter 1) observed size dimorphism in Pomacanthus paru, with males attaining larger sizes. Studying Pomacanthus paru in the Caribbean (St Croix, US Virgin Islands), Aiken (1983) states that males tend to mature later than females. This difference in size at maturity was also recorded by Feitosa et al. (unpublished data chapter 1). These authors affirm that individuals fit for reproduction appeared at 20 to 25 cm for females and 25 to 30 cm TL for males, with L 50 different between sexes,
being maturity reached at 30 cm for females and 35 cm for males. These findings corroborate with the present results, in which males presented lower K and had greater asymptotic length when compared to females.

Using size distributions of trap catches of the Gray angelfish, Pomacanthus arcuatus (Linnaeus, 1758) based on moderate samples from the unexploited sites of Pedro Bank and the Porto Royal reefs, Aiken (1983) determined that 60 cm TL is the asymptotic length. Although $P$. paru and $P$. arcuatus are sympatric species, maximal length ( $\mathrm{L} \infty$ ) was divergent, even considering that the $\mathrm{L} \infty$ established for $P$. arcuatus was based on total length. Aiken (1983) also examined scales from P. paru and found that rings or marks were present, but no interpretable pattern was discernible. The age and growth study of Pomacanthus imperator demonstrated that the $\mathrm{L} \infty$, based on standard length, for this specie is 41.19 cm (Chung \& Woo, 1999). This value is very large when compared with the $\mathrm{L} \infty$ recorded for Pomacanthus paru in this research.

Disparity between sets of growth parameters may be attributed to factors such as sample size, sample composition and the method employed to estimate growth parameters as well as divergences in population structure of different locations (Choat \& Robertson, 2002; Araújo \& Martins, 2006; Grandcourt et al., 2006). Some hypotheses may explain these differences, such as the method used by Aiken (1983) and Chung \& Woo (1999), which was length-frequency distribution in the former and the reading of scales in the latter. Another explanation is that $P$. paru occurs in the Atlantic, whereas $P$. imperator occurs in the Central and Indo-West Pacific (Allen et al., 1998). It is likely that differences in environmental (such as different water temperatures) and genetic characteristics can explain the contrast in growth parameters (Grandcourt et al., 2006). Due to the issues mentioned above, Laurec \& LeGuen (1981) state that growth
parameters are merely simple mathematical supports and have no value as biological characters a priori.
P. paru attains its maximal size slowly and has a long lifespan, with most linear growth achieved by approximately $52 \%$ of the lifespan. This growth pattern is shared by other reef fish (e.g. serranids, haemulids and lutjanids), which have K values ranging from 0.10 to 0.22 and maximal ages ranging from 9 to 16 years (Matheson et al., 1986; Munro \& Polunin, 1997). However, P. paru lives up to 10 years more and, in the case of males, the K value was smaller than that cited in the literature (Matheson et al., op. cit; Munro \& Polunin, op. cit). The low K value and long life among demersal fish suggests that these characteristics are associated to evolutionary success in the reef environment (Huntsman, 1981). According to Matheson et al. (1986), long life and relatively large body size maximize gamete and zygote production and allow reef fish to overcome the apparently low possibility of the pelagic offspring encountering a favorable habitat. Conversely, Cuban coastal reef fish, such as haemulids and lutjanids, have a short lifespan and a relatively high growth rate, with species reaching between 35 and $50 \%$ of maximal size in the first year of life, according to Claro \& GarcíaArteaga (2001). The authors suggest that these characteristics are related to adaptive mechanisms for avoiding predation on juveniles. Studying the coral trout Plectropomus leopardus (Lacepède, 1802) from the Great Barrier Reef, Australia, Ferreira \& Russ (1994) recorded a different survival mode in growth. This serranid is relatively shortlived. The growth rate becomes asymptotic from age six onwards and a substantial proportion of total growth is attained early in its life. This rapid growth is favored due to the availability of potential prey and avoidance of predators with the increase in body size. A similar pattern has been observed among scarids and acanthurids from the Great

Barrier Reef, for which growth patterns are highly deterministic and most linear growth is reached in the initial 10 to $20 \%$ of lifespan (Gust et al., 2002).
P. paru and other pomacanthids are heavily exploited by the aquarium trade (Moenick, 1991; Wood, 2001a; Monteiro-Neto et al., 2003). The family Pomacanthidae alone comprises $46 \%$ of exports by value (Pyle, 1993) and more than 21 species are harvested (Wood, 2001a). The French angelfish is a very important species in the Brazilian aquarium trade and is the second most exported species (Nottingham et al., 2000; Monteiro-Neto et al., 2003; IBAMA, 2007). In the USA (state of Florida), this species is managed through size regulations (Wood, 2001b). In Brazil, a Federal Act (56/04) was established in 2004 with the purpose of managing fishery activities targeting this species through the establishment of export quotas. The extended growth and late sexual maturity ( $\approx 23 \mathrm{~cm} \mathrm{TL}$ (female) - Feitosa et al., unpublished data; $\approx 11$ years old; 25 cm TL (male) - Feitosa et al., unpublished data; $\approx 15$ years old) of $P$. paru and other pomacanthids are angelfish characteristics that will render them vulnerable to extinction (Roberts \& Hawkins, 1999). As large-body specimens require a long time to grow, the removal of these specimens through predation or human activities is least likely to be recovered quickly (Chung \& Woo, 1999). Individuals of $P$. paru and other species collected for the aquarium trade are generally under 10 cm in standard length and rarely reach as much as 20 cm , which represents juveniles and young adults that have likely not reached sexual maturity (Wood, 2001b).

Chung \& Woo (1999) affirm that it was fortunate that the commercial exploitation of $P$. imperator has only focused on the aquarium trade. As individuals longer than $25 \mathrm{~cm}(\mathrm{SL})$ are rarely exploited and specimens up to 29.6 cm (SL) are still reproductively active, these fish constitute an important breeding stock if younger individuals are overexploited. However, this is not the case with P. paru. Besides the
impact from the ornamental fish trade, this species has been commonly caught as bycatch in trap fisheries for decades (Aiken, 1983; Feitosa et al., 2008). In this kind of fishery, more than $70 \%$ of individuals caught are fit for reproduction (Feitosa et al., 2008). Thus, it is possible that this species suffers fishing pressure at all length ranges and that this impact may threaten recruitment to the spawning stock. Besides, P. paru presents ecological importance. This species feeds on sponges and zoanthids (Palythoa) which compete with corals making their growth difficult.

In conclusion, the results demonstrate that it is possible to obtain estimates of growth for tropical species based on conventional age determination methods. These estimates should be used with the purpose of managing the fishery activity targeting this species. There are some management measures in place for the species throughout its range of distribution, which include size regulation (USA) and species-based exportation quotas (Brazil), all directed to the aquarium fish trade. While these regulations can clearly play an important role in helping to conserve stocks and prevent overexploitation, management measures should also include measures directed to other fisheries. In Brazil the species is commonly captured as bycatch in trap fisheries, an unregulated multi-specific fishery. Ornamental fish species are an important part of the bycatch (Feitosa el al., 2008). Those species are caught and usually returned to the sea many still alive, according to the fishermen. Survival of these individuals, however, is doubtful, as the traps are hauled quickly to surface and problems related to decompression have often been reported.

Monitoring and management of this fisheries, a growing activity with catches exported to the international market, is mandatory in order to assess the impact of this kind of fishery on both target and non-target species. This paper contributes to the knowledge on life history traits of $P$. paru, such as growth rates and age at sexual
maturity. Both are minimal requirements for effective fishery management regarding a given species. In the case of aquarium trade management, where most commercialized fish are juvenile and under than 10 cm in standard length, it can be suggested that conservationist issues should be based on quantitative data (capture) per area and the establishment of protected areas.

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## References

Aiken, K. (1983). The biology, ecology and bionomics of the butterfly and angelfishes, Chaetodontidae. In Caribbean coral reef fisheries resource. pp. 155 - 165. (J. L. Munro ed.) Iclarm studies and reviews 7: Manila, Philippines.

Aliaume, C., Zerbi, A., Joyeux, J. C., Miller, J. M. (2000). Growth of juvenile Centropomus undecimalis in a tropical island. Environmental Biology of Fishes 59, 299 -308 .

Allen, G. R., Steene, R., Allen, M. (1998). Introducing angelfish. In A guide to angelfishes \& butterflyfishes. pp. 8 - 12. Odyssey Publishing: USA/ Tropical Reef Research: Australia.

Allen, G. R., Steene, R., Allen, M. (1998). The Indo-West Pacific region. In A guide to angelfishes \& butterflyfishes. pp. 86. Odyssey Publishing: USA/ Tropical Reef Research: Australia.

Araújo, J. N., Martins, A. S. (2006). Age and growth of coney (Cephalopholis fulva), from the central coast of Brazil. Journal of the Marine Biological Association of the United Kingdom 86, 187-191.

Araújo, M. E. \& Albuquerque Filho, A. C. (2005). Biologia das principais espécies de peixes ornamentais marinhos do Brasil: uma revisão bibliográfica e documental. Boletim Técnico Científico do CEPENE 13, 109-154.

Arellano-Martínez, M., Ceballos-Vásquez, B. P., Garcia-Dominquez, F. and GalvánMagaña, F. (1999). Reproductive biology of the King Angelfish Holacanthus passer Valenciennes 1846 in the Gulf of California, Mexico. Bulletin of Marine Science 65, 677-685.

Bannerot, S., Fox Jr., W. W. \& Powers, J. E. (1987). Reproductive strategies and the management of snappers and groupers in the Gulf of Mexico and Caribbean. In Tropical snappers and groupers: biology and fisheries management (Polovina, J. J. \& Ralston, S eds.), pp. 561 - 603. Boulder: Westview Press.

Beamish, R. J. \& Fournier, D. A. (1981). A method for comparing the precision of a set of age determinations. Canadian Journal of Aquatic Science 38, 982 - 983.

Beamissh, R. J. \& McFarlane, G. A. (1987). The forgottens requirements for age validation in fisheries biology. Transactions of the American Fisheries Society 112, 735-743.

Bellwood, D. R., van Herwerden, L. \& Konow, N. (2004). Evolution and biogeography of marine angelfishes (Pisces: Pomacanthidae). Molecular Phylogenetics and Evolution 33, 140-155.

Brothers, E. B. (1980). Age and growth studies in tropical fishes. In Stock assessment for tropical small-scale fisheries, pp 119-136. University of Rhode Island: Kingston.

Casselman, J. M. (1987). Determination of Age and Growth. In The Biology of Fish Growth ( A.H. Weatherley and H. S. Gill Eds.), pp. pp. 209-242. London: Academic Press.

Cervigón, F. (1993). Pomacanthidae. pp. 339 - 346. In: Los Peces Marinos de Venezuela. Fundación Científica Los Roques, Caracas, 951pp.

Choat, J. H. \& Axe, L. M. (1996). Growth and longevity in acanthurid fishes, an analysis of otolith increments. Marine Ecology Progress Series 134, 15-26.

Choat, J. H., Axe, L. M. \& Lou, D. C. (1996). Growth and longevity in acanthurid fishes of the family Scaridae. Marine Ecology Progress Series 145, 33-41.

Choat, J. H. \& Robertson, R. (2002). Age based studies. In Coral reef fishes: dynamics and diversity in a complex ecosystem. pp. 57-80. San Diego: Academic Press.

Chung, K. C., Woo, N.Y.S. (1999). Age and growth by scale analysis of pomacanthus imperator (Teleostei: Pomacanthidae) from Dongsha Isllands, southern Chine. Environmtal Biology of Fish 55, 399 - 412.

Claro, R. \& García-Arteaga, J. P. (2001). Growth patterns of fishes of the Cuban shelf. In Ecology of the marine fishes of Cuba (R.Claro, K. C. Lindeman \& L. R. Parenti, eds.), pp.149-178. Washington: Smithsonian Institution Press.

Dee, A. J. \& Radtke, R. L. (1989). Age and growth of the bricke soldierfish, Myripristis amaena Coral reefs 8, 79-85.

Degens, E. T., Deuser, W. G. \& Haedrich, R. L. (1969). Molecular structure and composition of fish otoliths. Marine Biology 2, 105-113. Erickson, C. M. (1983). Age determination of Manitoban walleyes using otoliths, dorsal spines, and scales. North American Journal of Fisheries Management 3, 176-181.

Feitosa, C. V., Ferreira, B. P. \& Araújo, M. E. (2008). A rapid new method for assessing sustainability of ornamental fish by-catch from coral reefs. Marine and Freshwater Research 59, 1092-1100.

Feitoza, B. M., Rocha, L. A., Luiz-Júnior, O. J., Floeter, S. R. \& Gasparini, J. L. (2003). Reef fishes of St. Paul's Rocks: new records and notes on biology and zoogeography. Aqua, Journal of Ichthyology and Aquatic Biology 7, 61- 82.

Ferreira, B. P., Russ, G. R. (1992). Age, growth and mortality of the inshore coral trout, Plectropomus maculatus (Pisces: Serranidae) from the Central Great Barrier Reef, Australia. Australian Journal of Marine and Freshwater Research 43, 1301-1312. Ferreira, B. P., Russ, G. R. (1994). Age validation and estimation of growth rate of the coral trout, Plectropomus leopardus,(Lacépède 1802) from Lizard Island, Northern Great Barrier Reef. Fishery Bulletin 92, 46 - 57.

Fowler, A. J. \& Doherty, P. J. (1992). Validation of annual growth increments in the otoliths of two species of damselfish from southern Great Barrier Reef. Australian Journal of Marine and Freshwater Research 43, 1057-1068.

Grandcourt, E. M., Al Abdessalaam, T. Z. \& Francis, F. (2006). Age, growth, mortality and reproduction of the blackspot snapper, Lutjanus fulviflama (Forsskal, 1775), in the southern Arabian Gulf. Fisheries Research 78, 203 - 210.

Gust, N., Choat, J. H., Ackerman, J. L. (2002). Demographic plasticity in tropical reef fishes. Marine Biology 140, $1039-1051$.

Hart, A. M. \& Russ, G. R. (1996). Response of herbivorous fish to crown of thorns starfish Acanthaster planci outbreaks. III. Age, growth, mortality and maturity indices of Acanthurus nigrofuscus. Marine Ecology Progress Series 136, $25-35$.

Hernaman, V., Munday, P. L. \& Schläppy, M. L. (2000). Validation of otolith growthincrement periodicity in tropical gobies. Marine Biology 137, 715-726.

Huntsman, G. R. (1981). Ecological considerations influencing the management of reef fishes. In Artificial reefs: Conference proceedings. pp. 167 - 175. Sea Grant Report 41. IBAMA. (2007). http://www.ibama.gov.br/recursos-pesqueiros/wpcontent/files/quantidades_exportadas_2007_marinho.pdf

Laurec, A. \& LeGuen, J. C. (1981). Dynamique des populations marines exploitées. In Rapports Scientifiques et Techniques, 45. Centre National pour l'exploitation des Océans.

Longhurst, A. R. \& Pauly, D. (1987). Dynamics of Tropical Fish Populations. In Ecology of tropical oceans. pp. 300-306. Orlando: Academic Press

Lowenstein, O. (1971). The labyrinth. In Fish physiology (Hoar, W. S. \& Randall, D. J eds.) pp. 207-240. Academic Press: New York.

Matheson, R. H., Huntsman, G. R. \& Manooch, C. S. (1986). Age, growth, mortality, food and reproduction of the Scamp, Mycteroperca phenax, collected off North Carolina and South Carolina. Bulletin of Marine Science 38, 300-312.

Maugé, L. A. (1990) Pomacanthidae. p. 841. In Check-list of the fishes of the eastern tropical Atlantic (CLOFETA). (Quero, J.C., Hureau, J.C., Karrer, C., Post, A. \& Saldanha, L. eds.) JNICT, Lisbon, SEI, Paris; and UNESCO, Paris. Vol. 2. Menezes, N. A., Buckup, P. A., Figueiredo, J. L. \& Moura, R. L. (2003). Catálogo das espécies de peixes marinhos do Brasil. Museu de Zoologia USP, São Paulo.

Michael, S. W. (2004). Family Pomacanthidae/Angelfishes. In Angelfishes \& Butterflyfishes. pp. 296 - 323. T.F.H. Publications: New Jersey.

Moenich, D. R. (1991). Marine angels - Pomacanthus. T. F. H. Magazine 39, 68-81.
Monteiro Neto, C., Cunha, F. E. A., Nottingham, M. C, Araújo, M. E, Rosa, I. L. \& Barros, G. M. L. (2003). Analysis of the marine ornamental fish trade at Ceará State, northeast Brazil. Biodiversity and Conservation 12, 1287 - 1295.

Munro, J. L. \& Polunin, N. C. V. (1987). A decade of progress in coral reef fisheries research: 1986-1995. Proceedings of the $8^{\text {th }}$ International Coral Reef Symposium 2, 2003-2008.

Nottingham, M. C., Cunha, F. E. \& Monteiro Neto, C. (2000). Captura de peixes ornamentais marinhos no Ceará. Arquivos Ciências do Mar 33, 113-118.

Panella, G. (1971). Fish otoliths: daily growth layers and periodical patterns. Science, 137: 1124 - 1127.

Pyle, R. L. (1993). Marine aquarium fish. In Nearshore marine resources of the South Pacific. Information for fisheries development and management (Wright, A. \& Hill, L. eds). pp. 135-176. Institute of Pacific Studies: Suva and Forum Fisheries Agency: Honiara.

Radtke, R. L. (1987). Age and growth information available from the otoliths of the Hawaiian snapper, Pristipomoides filamentosus. Coral reefs 6, 19-25.

Randall, J. E. 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography Miami 5, 665-847.

Roberts, C. M. \& Hawkins, J. P. (1999). Extinction risk in the sea. Trends in Ecology and Evolution 14, 241-246.

Schwamborn, S. H. L. \& Ferreira, B. P. (2002). Age structure and growth of the dusky damselfish, Stegastes fuscus, from Tamandaré reefs, Pernambuco, Brazil. Enviromental Biology of Fishes 63, 79-88.

Six, L. D. \& Horton, H. F. (1977). Analysis of age determination methods for yellowtail rockfish, canary rockfish, and black rockfish off Oregon. Fishery Bulletin 75, 405-414. Thresher, R. E. (1982). Courtship and spawning in the Emperor Angelfish Pomacanthus imperator, with comments on reproduction by other pomacanthids fishes. Marine biology 70, 149-156.

Thresher, R. E. (1984). Angelfishes. In Reproduction in reef fishes. pp. 244 - 261. TFH Publications: New Jersey.

Wood, E. M. (2001a). Collection of coral reef fish for aquaria: global trade, conservation issues and management strategies. Marine Conservation Society, Ross-onWye: UK.

Wood, E. M. (2001b). Global advances in conservation and management of marine ornamental resources. Aquarium Sciences and Conservation 3, 65-77.

Williams, T. \& Bedford, B. C. (1974). The use of otoliths for age determination. In Ageing of fish (Bagenal, T. B ed.). pp.. 114-123., Old Woking: Gresham Press. Zekeria, Z. A., Weertman, S., Samuel, B., Kale-ab, T. \& Videler, J. J. (2006). Growth of Chaetodon larvatus (Chaetodontidae: Pisces) in the southern Red Sea. Marine Biology 148, 1113-1122.

# Capítulo 3 - Variabilidade do ADN mitocondrial em populações simpátricas das espécies ornamentais recifais do gênero Pomacanthus (Actinopyterigii: Pomacanthidae) no Atlântico Ocidental. 

Chapter 3* - Mitochondrial DNA variability in sympatric populations of the ornamental reef fish Pomacanthus (Actinopyterigii: Pomacanthidae) in the southwestern Atlantic.

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# Mitochondrial DNA variability in sympatric populations of the ornamental reef fish Pomacanthus (Actinopyterigii: Pomacanthidae) in the southwestern Atlantic 

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Running title: Mitochondrial DNA in populations of Pomacanthus

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#### Abstract

A number of studies have shown that reef fish populations have distinct color patterns, but these patterns are not associated with mt-DNA haplotypes. The aim of this study was to analyze the genetic diversity of Pomacanthus paru and P. arcuatus among populations of each species collected along the coast of northeastern Brazil. Thirty individuals were collected from coasts of Ceará, Pernambuco and Alagoas states. A region of the 16 S rDNA was amplified. For phylogenetic analyses additional sequences from four species of the genus Pomacanthus were obtained in GenBank. Six mitochondrial DNA haplotypes were found for $P$. paru and a single haplotype for $P$. arcuatus. Topologies indicate that $P$. paru haplotypes are monophyletic and Pomacanthus species constitute a monophyletic group. The single haplotype of $P$. arcuatus was shared by individuals sampled in Pernambuco, Ceará (northeastern coast of Brazil) and the Caribbean. The considerations presented here represent a first step toward understanding the population structures of the sister species Pomacanthus paru and P. arcuatus. Complementary studies on larval settlement, physiological characteristics and anthropogenic actions directed at these populations are needed for a greater understanding of the dynamics of these species.


Keywords: mt-DNA, haplotypes, diversity, Pomacanthus paru, Pomacanthus arcuatus

## Introduction

Biodiversity based on morphology alone may considerably underestimate evolutionary lineages, particularly when morphological stasis persists after speciation events. This results in species that continue to diverge genetically in the absence of morphological differentiation, producing cryptic or sibling species (Knowlton 1986). Our inability to recognize cryptic species with traditional morphological characters has hindered our understanding of ecological and evolutionary processes. The negative consequences include underestimation of true levels of species-richness, overestimation of potential for long-distance dispersal in supposedly cosmopolitan species, failure to recognize cryptic biological invasions, and misinterpretation of ecological data (Knowlton et al 1992; Geller et al 1997; Rocha-Olivares et al 2001). Even when changes in allele frequencies and differences in sequence data among populations are not considered sufficient for attributing species-level status, organism and population genetic changes must represent the first steps linking micro-phylogeny with macro-phylogeny, because population genetics and phylogenetic history must in truth be parts of a temporal continuum (Avise 2009).

Most marine habitats have traditionally been thought to be highly interconnected by gene flow, because of the absence of obvious barriers to migration and because many marine taxa have pelagic larval stages that have been considered passive dispersers (Palumbi 1994). In contrast, high levels of biodiversity in marine systems suggest that genetic divergence and eventual speciation may be common and rapid in marine systems, indicating that marine biodiversity is actually much higher than earlier estimates (Mathews 2006).

Molecular genetic technologies have changed the way we describe and catalogue biological diversity. Mitochondrial sequence data has sometimes indicated no genetic structure within species (McMillen-Jackson and Bert, 2003), but usually points to an
increasing diversity of lineages, from two- to nineteen and perhaps more genetic or specific lineages (e.g., Rocha-Olivares et al 1999; Bichain et al 2007; Rocha et al 2008; Mathews and Anker 2009). When mitochondrial DNA differences become correlated with nuclear DNA sequence patterns, differences in geographical distribution, color distinctions, ecological and behavioral data, or even slight but constant morphological differences, such congruent evidence has be used to establish the presence of distinct evolutionary lineages (Mathews et al 2002; Sandoval-Castillo et al 2004; Thompson et al 2005).

Phylogeography, the geographical study of population genetics, is now a burgeoning discipline that is establishing a conceptual bridge between microevolutionary population genetics and macroevolutionary phylogenetics and historical biogeography (Avise 2009). These studies have the power to yield insights into the past as well as present evolutionary processes, having been used to uncover information about the roles of geographical history and ecology in generating marine species diversity (e.g., Williams and Reid 2004).

Phylogeography has triggered a renewed interest in speciation processes affecting Neotropical coral reef fish (Taylor and Hellberg 2005; Rocha and Bowen 2008). Reef fish are characterized by their bright and diversified coloration (Sale 1991). Many polytypic species are the result of fragile diagnoses and may include subspecies (Wiley 1981).

Comparing Brazilian populations of two species of reef fish that inhabit the Rocas atoll and the coast of the state of Ceará, Freitas et al (2003) differentiated fish stocks in Acanthurus chirurgus, but found unrestricted gene flow among the populations of Cephalopholis fulva. The majority of marine organisms are dispersed in the form of pelagic larvae that travel long distances by way of ocean currents. Upon reaching adulthood, many reef fish are benthic, territorial and remain associated with reef substrates (e.g. Sale 1980; Doherty and Williams 1988).

Species of the genus Pomacanthus occur in tropical and subtropical waters around the world (Allen et al 1998). Among the thirteen species of this genus, only $P$. paru and $P$. arcuatus occur in the Western Atlantic (Allen 1979; Allen et al 1998; Menezes et al 2003). There is agreement that these species generally share the same habitat and their home ranges overlap (Moyer et al 1983; Hourigan et al 1989). However, authors disagree with regard to the behavior between the two species. Moyer et al (1983) have recorded aggressive postures, whereas Hourigan et al (1989) found no agonistic behavior between the two species. Sympatric sister species such as $P$. paru and $P$. arcuatus can form hybrids and, although there is no record of a wild hybrid between these species (Deloach 1999), some have been produced in captivity (Moe 1976).

The aims of the present study were to analyze the mitochondrial DNA genetic diversity of $P$. paru and $P$. arcuatus and to determine whether there is geographic structuring of this diversity among the populations of each species collected at three sites along the coast of Brazil.

## Materials and Methods

Thirty specimens of $P$. paru and $P$. arcuatus were analyzed in the present study. All specimens were collected on the coast of the states of Ceará, Pernambuco and Alagoas (Fig. 1). Thirteen were collected from a single site in Ceará (seven $P$. paru and six $P$. arcuatus). Among these $P$. paru specimens, there were two individuals (belonging to Haplotype Hp1) with a different color pattern (more grayish).

Fourteen of the specimens (12 P. paru and two $P$. arcuatus) were acquired from the Itamaracá Island Fishing Colony in the state of Pernambuco $\left(7^{\circ} 45^{\prime} 17.80^{\prime \prime}\right.$ S-
$34^{\circ} 49^{\prime} 26.46^{\prime}$ ' W). The remaining three specimens were $P$. paru from the state of Alagoas. The specimens from Alagoas and Ceará were donated by the proprietors of the aquarium trade companies D'água and H\&K Ornamental Fishes, respectively, who offered no information on the coordinates of the collection sites (Fig. 1).


Figure 1: Location of sampled area. CE - Ceará state, PE - Pernambuco state and AL Alagoas state.

Muscle and liver samples from each individual were stored in liquid nitrogen at the Laboratory of Applied Genetics of the Fishery Department of the Universidade Federal Rural de Pernambuco (UFRPE). The DNA extraction procedure followed the standard protocol described by Sambrook et al. (1989). Besides the collected specimens, sequences from the

GenBank were used for the specimens of $P$. arcuatus (AY530868 from the Caribbean) and $P$. paru (AY530852 from Belize) (Bellwood et al 2004).

A region of the 16 S rDNA was amplified with the primers described by Simon et al. (1994): LR-J-12887 5`-CCG GTC TGA ACT CAG ATC ACG T-3` and LR-N-13398 5` CGC CTG TTT ACC AAA AAC AT 3`. PCR reactions were carried out as described in Bellwood et al. (2004). PCR products were purified using the GFX PCR DNA \& Gel Band Purification Kit (GE-Healthcare) and sequenced in both directions using the DYEnamic ET Terminator Sequencing kit (GE-Healthcare) in an ABI-377 automated sequencer.

For the phylogenetic analyses, additional 16 S rDNA sequences from four species of the genus Pomacanthus were obtained from the GenBank: $P$. asfur (AY530854), $P$. semicirculatus (AY530844), P. sexstriatus (AY530858) and P. zonipectus (AY530874). Sequences from Chaetodontoplus duboulayi (AY530846) and Centropyge flavissimus (AY530841) were used as outgroups. Nucleotide alignment was carried out by eye. A distance tree was constructed by neighbor-joining, with Kimura 2-parameter distance estimates, using the Mega 4.0 program (Tamura et al 2007). Parsimony topology was obtained using PAUP 4.0 (Swofford 1998). The bootstrap test (1000 replicates) was used in both analyses to evaluate node robustness. Network analysis was carried out for P. paru and P. arcuatus haplotypes, using the TCS software Phylogenetic Network Estimation Using Statistical Parsimony (Clement et al 2000). The choice of the ancestral haplotype was based on the central position in the network analysis as well as on frequency (Crandall and Templeton 1996). Haplotype diversity, nucleotide diversity indexes (Nei 1987), and Fu's Fs test of selective neutrlity were estimated and carried out with the Arlequin 3.01 program (Excoffier et al 2005).

## Results

Six mitochondrial DNA haplotypes were found for P. paru (Haplotype Diversity, h= 0.67; Nucleotide Diversity, $\pi=0.0018$ ) and a single haplotype was found for P. arcuatus (Table 1). Neighbor-joining and parsimony topologies (tree length $=154$ steps; Consistency Index $=0.81$ ) indicate that $P$ paru haplotypes are monophyletic and $P$. paru and $P$. arcuatus are sister species. These topologies had a similar arrangement (Fig. 2), revealing Pomacanthus species to be in a monophyletic group and $P$ zonipectus grouped with $P$ paru and $P$ arcuatus.

Table 1: Variable sites found in haplotypes of $P$. paru (Hp 1-6) and $P$. acuatus (Ha 1) and number of individuals sharing a same haplotype per locality. Sequences from the Belize specimen belonging to Hp 4 haplotype and the specimen from P. arcuatus from the Caribbean were obtained from GenBank.

| Haplotype | Variable position | Specimens / Locality |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{array}{r} 111111222233344 \\ 2016667366826634 \\ 6901679669235766 \end{array}$ | Ceará (CE) | Pernambuco (PE) | Alagoas (AL) | Caribbean |
| P. paru |  |  |  |  |  |
| Hp 1 (11) | CTACGTA-GACAT-GC | 4 | 5 | 2 |  |
| Hp 2 (1) | ..T....-....- |  | 1 |  |  |
| Hp 3 (1) | . . . . . - . . C -. |  |  | 1 |  |
| Hp 4 (1) | . . . . . - . . . T. |  |  |  | 1 |
| Hp 5 (8) | ......-.G...-. | 2 | 6 |  |  |
| Hp 6 (1) | T.....-.G...-. | 1 |  |  |  |
| P. arcuatus |  |  |  |  |  |
| Ha 1 (9) | . - . TTCGAT.GT.-AT | 6 | 2 |  | 1 |



Figure 2: Neighbor-Joining (A) and Parsimony (B) topologies based on 16 S rDNA mitochondrial sequences for the haplotypes of Pomacanthus paru and Pomacanthus arcuatus, and other Pomacanthus species. C. flavissimus - Centropyge flavissimus and C. dubolayi Chaetodontoplus duboulayi were used as outgroups. Localities where the haplotypes were found are indicated between parenthesis: AL - Alagoas state, Brazil; CE - Ceará state, Brazil; PE - Pernambuco state, Brazil; and Caribbean. DC indicates specimens of P. paru with grayish coloration.

Concerning the six P. paru haplotypes, two had a greater frequency (Hp1 and Hp5, Table 1), with Hp1 present at all sample sites (Ceará, Pernambuco, and Alagoas). The network analysis (Fig. 3) suggests that Hp 1 is the ancestral haplotype. The single haplotype of P. arcuatus (Ha1) was shared by individuals captured at two sites along the northeastern coast of Brazil (Pernambuco and Ceará) and is the same haplotype found in a Caribbean specimen.


Figure 3: Parsimony Network of the mitochondrial haplotypes from Pomacanthus paru and P.arcuatus. The circles represent the haplotypes and the diameter is proportional to the number of specimens carrying each haplotype, except for $P$. arcuatus (Ha 1). Nucleotide substitutions between haplotypes were indicated.

The Fu's Fs test of selective neutrality for $P$. paru was significant marginally: Fs test $=-$ 2.35 and $\mathrm{P}=0.022$ (Fs is significant when $\mathrm{P}<0.02$ ) ( Fu , 1997).

## Discussion

## Phylogeny

The molecular results obtained here indicate that $P$. arcuatus is a well-defined group, with only one haplotype identified, whereas the $P$. paru individuals form an independent
clade with at least six haplotypes for the tropical southwestern Atlantic. The negative Fs value and the star-like network indicate a demographic expansion for $P$. paru populations. This hypothesis can also be extended to $P$. arcuatus with only one haplotype.

## Genetic structure of species

In the tropical southwestern Atlantic the Pomacanthus species complex shows strong genetic heterogeneity in the populations belonging to oceanic islands, presently identified as P. paru, and genetic homogeneity in coastal populations classified as $P$. arcuatus. Coastal populations of Pomacanthus thus appear to be genetically less diverse than offshore populations of this species, paralleling results recently obtained for dolphins in the Gulf of California (Segura et al 2006). These fish species may be the result of range shifts and secondary contact after allopatric speciation, or may be indicative of parapatric ecological speciation. On the whole, $P$. paru appears to have undergone some genetic differentiation into distinct haplotypes, although the occurrence of a same haplotype in different geographical localities indicates an incomplete differentiation into distinct populations.

In a single species, the number of haplotypes may vary considerably. The calculation proposed by Nei (1987) for haplotype diversity ( $h$ ) demonstrates that the greater it is, the greater the selective pressure on a given population will be and the more it will grow (Bowen et al., 2006). These authors consider the haplotype diversity among species of the genus Centropyge to be high ( $h=0.991-1.0$ ) ( 14 in C. argi, 15 in C. resplendens and 17 in $C$. aurantonotus). As the authors analyzed a region of mt-DNA (d-loop) that is more variable than that analyzed in the present study ( 16 S rDNA), the value obtained for $P$. paru ( $h=$ 0.6719 ) could be higher if the d-loop were the molecular segment analyzed.

The present paper recognizes 6 previously unidentified haplotypes within the species $P$. paru. These evolutionary units are presently suggested by genetic divergence in the
mitochondrial DNA (shifts in allele frequencies). Independent lines of research are needed in order to determine if some of these haplotypes may indicate population and species level separations (for example, constant color pattern differences, morphological differences, or reproductive isolation data). Our data are still inconclusive in this respect. Genetic data from samples collected along the entire ranges of the species are still needed in order to establish such ecological and geographical patterns more precisely. The identification of discrete genetic lineages within a widely distributed species is often followed by the discovery of previously unobserved morphological differentiation (genealogical concordance, and subsequent recognition of the lineages as valid species (Rocha et al 2007). Our data increase our awareness of the net biodiversity in the marine environment of the tropical southwestern Atlantic, although we have so far been unable to associate color differences with population genetic differences within $P$. paru.

The genetic pattern observed in $P$. paru may not correspond to the species evolutionary history, but merely to the history of the mitochondria (Ballard and Whittock 2004). How differentiated conspecific lineages should be before they are elevated to species level is an unresolved question, and taxonomic decisions should thus be based on the congruence of independent data sets (e.g., including sequence data from nuclear genomes, color and morphological differences, data from ecological partitions and geographical separations), rather than on absolute levels of genetic divergence.

## Color Patterns

Mutations in genes that control morphological features, such as color, are commonly used to differentiate populations of marine animals (Knowlton and Mills 1992; Losos et al 1998, Endler et al 2005). The two individuals of $P$. paru sampled along the littoral of the state of Ceará with a distinct more grayish color pattern represent only a small fraction of our Hp 1
haplotype. This could indicate that (1) there is no correlation between haplotype and color pattern, or (2) that there is further hierarchical structure undetected with molecular markers within $P$. paru.

A number of studies have shown that many fish populations have distinct color patterns, but these patterns are not associated with mt-DNA haplotypes (e.g., Rocha et al 2005; 2007; Schultz et al 2007). As far as our data indicate, this seems to be the case also for Pomacanthus. According to Rocha et al. (2007), there are two alternative explanations for this: 1) disruptive natural selection for color pattern (McCartney et al 2003; Ramon et al 2003); and 2) hybridization among color morphotypes (Puebla et al 2007). Although many species of reef fish are described based on their color patterns, morphological and genetic studies are essential for their diagnosis (Rocha 2004; Lima et al 2005).

## Distribution and Ecology

Although the geographic distribution of these species coincides, P. arcuatus is recorded at greater latitudes in the northern hemisphere (New York), whereas P. paru (from Florida) reaches greater latitudes in the southern hemisphere. In Brazil, the latter species occurs as far as the state of Santa Catarina ( $26^{\circ} 58^{\prime} 01.67^{\prime} \mathrm{S}$ and $49^{\circ} 22^{\prime} 23.45^{\prime}{ }^{\prime} \mathrm{W}$ ), whereas $P$. arcuatus only occurs as far south as the state of Espírito Santo ( $19^{\circ} 11^{\prime} 22.84^{\prime \prime} \mathrm{S}$ and $40^{\circ} 18^{\prime} 33.50^{\prime}$ 'W) (Menezes et al 2003). Pomacanthus paru is the only species in this genus to occur in Brazilian oceanic islands, such as the Rocas atoll (Rosa and Moura 1997) and St. Peter and St. Paul's Rocks (Feitoza et al 2003). The two species differ in abundance. P. paru is more common along the Brazilian coast (Carvalho Filho 1999, Ferreira et al 2004) and less common in the Caribbean (Smith 1997) in comparison to P. arcuatus. This observation was confirmed by Hourigan et al. (1989), who carried out a transect census in the Caribbean (St. Croix, US Virgin Islands) and obtained a greater average density for $P$. arcuatus
$(0.56 / 1000 \mathrm{~m} 2)$ in comparison to $P$. paru $(0.31 / 1000 \mathrm{~m} 2)$. Based on the fact that $P$. arcuatus is more frequent in the Caribbean, it is possible that $P$. paru is more apt to occupy more recent habitats, such as those found along the Brazilian coast.

For a definitive picture of management units within $P$. paru, it will be necessary to survey the entire geographical and ecological range of the species, in order to fully understand the phylogeography, or geographical distribution of genetic lineages. For cases in which sibling species complexes occur in sympatry and show no clear differences in ecological specialization, Gittenberger (1991) has used the term nonadaptive radiation.

The partial overlap between the geographical ranges of $P$. acuatus and $P$. paru, and also among the haplotypes of the latter species, indicates that conventional allopatric speciation by biogeographical barriers (e.g., Bernardi et al 2003) is not the only explanation for the speciation of tropical reef fishes. Parapatric ecological speciation by habitat partitioning at a local scale represents a mechanism that may explain the long-standing enigma of high biodiversity in coral reef faunas (Rocha et al 2005).

## Conclusions

Our data support the phylogenetic proximity between Pomacanthus paru and $P$. arcuatus and corroborate morphological, ethological (Pyle and Randall 1994), enzymatic (Chung and Woo 1998) and chromosomal (Galetti et al 2006) patterns. The molecular phylogeographical results of the present study confirm the taxonomic status of these sister species and suggest that, although they are sympatric (frequently syntopic), they have different evolutionary histories.

The considerations presented here represent a first step toward understanding the population structures of the sister species Pomacanthus paru and P. arcuatus, which have
economic value as ornamental fish. Complementary studies on larval settlement, physiological characteristics and anthropogenic actions directed at these populations are needed for a greater understanding of the dynamics of these species. The knowledge obtained herein on genetic distinctions into distinct haplotypes of $P$. paru has important conservation implications, considering that population diversity of this commercial fish may be larger than previously thought.

Although our paper deals primarily with the intraspecific genetic diversity of a commercial group of reef fish, stretches of mtDNA have nevertheless been shown to have tree-like histories within a species, and the branching structures of these gene genealogies may bear considerable analogy to phylogenetic trees summarizing historical relationships among reproductively isolated taxa and higher taxa, albeit on a different time scale (Avise 2009).

## References

Allen GR, 1979. Butterfly and angelfishes of the world. Melle: Mergus Publishers, Melle.
Allen GR, Steene R, Allen M, 1998. A guide to angelfishes \& butterflyfishes. USA: Odyssey Publishing/Australia:Tropical Reef Research.

Avise JC, 2009. Phylogeography: Retrospect and Prospect. J Biog. 36: 3-15.
Ballard JW, Whitlock MC, 2004. The incomplete natural history of mitochondria. Mol Ecol. 13:729-744.

Bellwood DR, van Herwerden L, Konow N, 2004. Evolution and biogeography of marine angelfish (Pisces: Pomacanthidae). Mol Phylogen Evol. 33:140-155.

Bernardi G, Findley L, Rocha-Olivares A, 2003. Vicariance and dispersal across Baja California in disjunct marine fish populations. Evolution 57:1599-1609.

Bichain JM, Boisselier-Dubayle MC, Bouchet P, Samadi S, 2007. Species delimitation in the genus Bythinella (Mollusca : Caenogastropoda : Rissooidea): a first attempt combining molecular and morphometrical data. Malacologia 49: 293-311.

Bowen BW, Muss A, Rocha LA, Grant WS, 2006. Shallow mtDNA coalescence in Atlantic pygmy angelfishes (Genus Centropyge) indicates a recent invasion from the Indian Ocean J Hered. 97:1-12.

Carvalho-Filho A, 1999. As espécies e suas famílias. In: Peixes: Costa Brasileira. São Paulo: Editora Melro. p. 40-83.

Chung KC, Woo NYS, 1998. Phylogenetic relationships of the Pomacanthidae (Pisces: Teleostei) inferred from allozyme variation. J Zool. 246:215-231.

Clement M, Posada D, Crandall K A, 2000. TCS: a computer program to estimate gene 6 genealogies. Mol Ecol. 9:1657-1659.

Crandall KA, Templeton AR, 1996. New uses for new phylogenies. UK: Oxford University Press

Deloach N, 1999. Reef fish behavior: Florida, Caribbean, Bahamas. Florida (USA): New World Publication.

Doherty PJ, Williams DMB, 1988. The replenishment of coral reef fish populations. Annu Rev Oceanogr Mar Biol. 26:487-551.

Endler JA, Wescotte DA, Madden JR, Robson T, 2005. Animal visual systems and the evolution of color patterns: sensory processing illuminates signal evolution. Evolution 59:1795-1818.

Excoffier L, Laval G, Schneider S, 2005. Arlequin ver. 3.0: An integrated software package for population genetics data analysis. Evol Bioinf Online 1:47-50.

Feitoza BM, Rocha, LA, Luiz-Júnior OJ, Floeter SR, Gasparini JL, 2003. Reef fishes of St. Paul's Rocks: new records and notes on biology and zoogeography. Aqua, J Ichth Aquat Biol. 7:61-82.

Ferreira CEL, Floeter SR, Gasparini JL, Joyeux JC, Ferreira BP, 2004. Trophic structure patterns of Brazilian reef fishes: a latitudinal comparison. J Biogeogr. 31:1093-1106. Freitas JEP, Araújo ME, Solé-Cava AM, 2003. Estruturação genética das populações de duas espécies de peixes recifais do Atol das Rocas e da costa do Ceará. Trop Oceanogr. 31:193201.

Fu YX, 1997. Statistical tests of neutrality of mutations against population growth, hitchhiking, and background selection. Genetics 147:915-925.

Galetti Jr PM, Molina WF, Affonso PRAM, Aguilar CT, 2006. Assessing genetic diversity of Brazilian reef fishes by chromosomal and DNA markers. Genetica 126:161-177.

Geller JB, Walton ED, Grosholz ED, Ruiz GM, 1997. Cryptic invarions of the crab Carcinus detected by molecular phylogeography. Mol Ecol. 6:901-906.

Gittenberger E, 1991. What about nonadaptive radiation ? Biol J Linn Soc. 43:263-272. Hourigan TF, Stanton FG, Motta PJ, Kelley CD, Carlson B, 1989. The feeding ecology of three species of Caribbean angelfishes (family Pomacanthidae). Env Biol Fish 24:105-116. Knowlton N, 1986. Cryptic and sibling species among the decapod Crustacea. J Crust Biol. 6:356-363.

Knowlton N, Mills EEK, 1992. The systematic importance of color and color pattern: Evidence for complexes of sibling species of snapping shrimp (Caridea: Alpheidae: Alpheus) from the Caribbean and Pacific coasts of Panama. Proc San Diego Soc Nat Hist 18:1-5. Knowlton N, Weil E, Weigt LA, Guzman HM, 1992. Sibling species in Montastrea annularis, coral bleaching, and the coral climate record. Science 255:330-333.

Lima D, Freitas JE, Araujo ME, Solé-Cava AM, 2005. Genetic detection of cryptic species in the frillfin goby Bathygobius soporator. J Exp Mar Biol Ecol. 320:211-223.

Losos JB, Jackman TR, Larson A, de Queiroz K, Rodriguez-Schettino L, 1998. Contingency and determinism in replicated adaptive radiations of Island lizards. Science 279:2115-2118. Mathews LM, 2006. Cryptic biodiversity and phylogeographical patterns in a snapping shrimp species complex. Mol Ecol. 15:4049-4063.

Mathews LM, Anker A, 2009. Molecular phylogeny reveals extensive ancient and ongoing radiations in a snapping shrimp species complex (Crustacea, Alpheidae, Alpheus armillatus). Mol Phylog Evol. 50: 268-281.

Mathews LM, Schubart CD, Neigel JE, Felder DL, 2002. Genetic, ecological, and behavioural divergence between two sibling snapping shrimp species (Crustacea, Decapoda: Alpheus). Mol Ecol. 11:1427-1437.

McCartney MA, Acevedo J, Heredia C, Rico C, Quenouille B, Bermingham E, McMillan WO, 2003. Genetic mosaic in a marine species flock. Mol Ecol. 12:2963-2973.

Mcmillen-Jackson AL, Bert TM, 2003. Disparate patterns of population genetic structure and population history in two sympatric penaeid shrimp species (Farfantepenaeus aztecus and Litopenaeus setiferus) in the eastern United States. Mol Ecol. 12:2895-2905.

Menezes NA, Buckup PA, Figueiredo JL, Moura RL, 2003. Catálogo das espécies de peixes marinhos do Brasil. Museu de Zoologia USP, São Paulo.

Moe MA, 1976. Rearing Atlantic angelfish. Mar Aquar. 7: 17-26.
Moyer JT, Thresher RE, Colin PL, 1983. Courtship, spawning and inferred social organization of American angelfishes (genera Pomacanthus, Holacanthus and Centropyge; Pomacanthidae). Env Biol Fish 9:25-39.

Nei M, 1987. Molecular evolutionary genetics. New York: Columbia University Press.

Palumbi SR, 1994. Genetic divergence, reproductive isolation, and marine speciation. Ann Rev Ecol System. 25:547-572.

Puebla O, Bermingham E, Guichard F, Whiteman E, 2007. Colour pattern as a single trait driving speciation in Hypoplectrus coral reef fishes? Proc. R. Soc. Lond. B. 274:1265-1271. Pyle RL, Randall JE, 1994. A review of hybrization in marine angelfishes (Perciformes: Pomacanthidae). Env Biol Fish 41:127-145.

Ramon ML, Lobel PS, Sorenson MD, 2003. Lack of mitochondrial genetic structure in hamlets (Hypoplectrus spp.): recent speciation or ongoing hybridization? Mol Ecol. 12:29752980.

Rocha LA, 2004. Mitochondrial DNA and color pattern variation in three western Atlantic Halichoeres (Labridae), with the revalidation of two species. Copeia 2004:770-782.

Rocha LA, Bowen BW, 2008. Speciation in coral-reef fishes. J Fish Biol. 72: 1101-1121.
Rocha LA, Craig MT, Bowen BW, 2007. Phylogeography and the conservation of coral reef fishes. Coral Reefs, 26:501-512.

Rocha LA, Robertson RD, Roman J, Bowen BW, 2005. Ecological speciation in tropical reef fishes. Proc R Soc B. 272:573-579.

Rocha LA, Rocha CR, Robertson DR, Bowen BW, 2008. Comparative phylogeography of Atlantic reef fishes indicates both origin and accumulation of diversity in the Caribbean. Bmc Evolutionary Biology 8: Art. 157. [cited 2009 March 5] Available from:
http://creativecommons.org/licenses/by/2.0.
Rocha-Olivares A, Fleeger JW, Folz DW, 2001. Decoupling of molecular and morphological evolution in deep lineages of a meiobenthic harpacticoid copepod. Mol Biol Evol. 18: 10881102.

Rocha-Olivares A, Rosenblatt RH, Vetter RD, 1999. Cryptic species of rockfishes (Sebastes : Scorpaenidae) in the southern hemisphere inferred from mitochondrial lineages. J Hered. 90: 404-411.

Rosa RS, Moura RL, 1997. Visual assessment of reef fish community structure in the Atol das Rocas Biological Reserve, off Northeastern Brazil. Proc $8^{\text {th }}$ Internat Coral Reef Symp 1:983986.

Sale PF, 1980. The ecology of fishes on coral reefs. Annu Rev Oceanogr Mar Biol. 18:367421.

Sale PF, 1991. The Ecology of Fishes on Coral Reefs. San Diego: Academic Press.
Sambrook J, Fritsch EF, Maniatis T, 1989. Molecular cloning: A Laboratory Manual. New York: Cold Spring Habor lab.

Sandoval-Castillo J, Rocha-Olivares A, Villavicencio-Garayzar C, Balart E, 2004. Cryptic isolation of Gulf of California shovelnose guitarfish evidenced by mitochondrial DNA. Mar Biol. 145: 983-988.

Schultz JK, Pyle RL, DeMartini E, Bowen BW, 2007. Genetic connectivity among color morphs and Pacific archipelagos for the flame angelfish, Centropyge loriculus. Mar Biol. 151:167-175.

Segura I, Rocha-Olivares A, Flores-Ramirez S, Rojas-Bracho L, 2006. Conservation implications of the genetic and ecological distinction of Tursiops truncatus ecotypes in the Gulf of California. Biol Cons 133:336-346.

Smith CL, 1997. National Audubon Society field guide to tropical marine fishes of the Caribbean, the Gulf of Mexico, Florida, the Bahamas, and Bermuda. New York: Alfred A. Knopf, Inc.

Swofford DL, 1998. PAUP*: Phylogenetic analysis using parsimony (and other methods). Sunderland, MA: Sinauer Associates.

Tamura K, Dudley J, Nei M, Kumar S, 2007. MEGA4: Molecular evolutionary genetics analysis (MEGA) software version 4.0. Mol. Biol Evol. 24:1596-1599. Taylor MS, Hellberg ME, 2005. Marine radiations at small geographic scales: speciation in Neotropical reef gobies (Elacatinus). Evolution 59:374-385.

Thompson AR, Thacker CE, Shaw EY, 2005. Phylogeography of marine mutualists: parallel patterns of genetic structure between obligatory goby and shrimp partners. Mol Ecol. 14: 3557-3572.

Wiley EO, 1981. Phylogenetics: the theory and practice of phylogenetic systematics. USA: John Wiley \& Sons, Inc.

Williams ST, Reid DG, 2004. Speciation and diversity on tropical rocky shores: a global phylogeny of snails of the genus Echinolittorina. Evolution 58:2227-2251.

Capítulo 4 - Um método novo e rápido para avaliar a sustentabilidade do bycatch de peixes ornamentais dos recifes de corais.

Chapter $4 * \dagger$ - A rapid new method for assessing sustainability of ornamental fish bycatch from coral reefs.

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Catch sustainability of ornamental fish bycatch...

# A rapid new method for assessing sustainability of ornamental fish bycatch from coral reefs. 

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#### Abstract

The ornamental fish trade has a considerable potential for damaging reef environments. Nearly 120 species are currently harvested in the Brazilian trade and little attention has been paid to the effects of the accidental catch of these species. Records of ornamental fish bycatch and the susceptibility and resilience of species from the major Brazilian families in the aquarium trade were examined to test a method and determine the sustainability of these catches. Each species was assessed based on two groups of criteria: (1) relative vulnerability to capture; and (2) population resilience regarding mortality due to fishing efforts. Each species was also ranked (1-3) based on individual criteria regarding ecology, biology, catchability, numbers of individuals exported by aquarium companies and mortality index. These criteria were then weighted and each species rank in the two groups of criteria was plotted. Nineteen species from 10 families were recorded. The species least likely to have sustainable catch rates were Holacanthus tricolor, H. ciliaris, Chaetodon striatus and Pomacanthus paru. This approach is a useful alternative for management efforts and the assessment of catch sustainability in newly-developed multi-species fisheries with limited available data, which occur in areas of high species richness such as reefs.


25 Additional keywords: aquarium, trap, fishery, susceptibility, resilience, Pomacanthidae, Chaetodontidae.

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## Introduction

Species classified as bycatch (Eayrs 2007) are caught in fisheries that target other groups and are then either used or discarded. It is estimated that 7.3 million tonnes of fish were discarded globally in commercial fisheries in the period of 1995-2005 (Kelleher 2005). This is equivalent to $8 \%$ of worldwide marine fish production (Eayrs 2007). The global effect of fisheries on bycatch species is poorly known, although some studies have documented ecological changes on the species level (Casey and Myers 1998; Pope et al. 2000). Even less attention has been paid to accidental catches affecting reef fish, including ornamental species.

Beauty and perfect patterns on ornamental reef fish are requirements imposed by the international aquarium trade (Araújo and Albuquerque Filho 2005), which is one of the world's largest industries. The import value worldwide of marine fish and invertebrates is estimated to be between US\$ 24 and 40 million annually (Wood 2001a). Nearly 120 species are currently harvested in the Brazilian aquarium trade (Monteiro Neto et al. 2003). Most belong to the Pomacanthidade family (Araújo and Albuquerque Filho 2005), while the Chaetodontidae are among the most exported (Monteiro Neto et al. 2003; Nottingham et al. 2000). Although other fisheries that use traps have an effect on ornamental marine fish stocks (through by-catch), these stocks have only been managed through a Federal Act (56/04, established in 2004 by the Brazilian environmental protection agency - Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA) that monitors ornamental fish trade through export quotas. The purpose of this Federal Act is to administer this activity through the establishment of export quotas.

Traps are the predominant gear employed to capture reef fish in the Caribbean (Swingle et al. 1970; Garrison et al. 1998) as well as other places in the world (e.g. Arabian Gulf, Seychelles, Papua New Guinea) (Dalzell 1996) and are responsible for the decline of many reef species, which are fishery targets (Wolff et al. 1999). Among the organisms caught by these devices, the most frequently caught ornamental fish belong to the following genera: Acanthurus, Chaetodon, Bodianus, Holacanthus and Pomacanthus (Garrisson et al. 1994; Wolff et al. 1999). In Brazil, trap fisheries targeting reef fish have been on the rise in the last ten years (Ribeiro 2004). The target

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species of these fisheries belong to the genera Acanthurus, Cephalopholis, Lutjanus, Pseudupeneus and Sparisoma (Ribeiro 2004). Because by-catch, including ornamental species, is returned to the sea and not recorded, there are no data or regulations available about the actual catch of ornamental species.

Due to the increasing pressure to manage the impact of fisheries on non-target species and the uncertainty of how this is to be done, Stobutzki et al. (2001) has developed a broad method using qualitative measures of the biological and ecological characteristics of species to rank vulnerability to a known threat. These authors examine the impact of trawling on the catch sustainability of teleost bycatch species, identifying the species with the least likelihood of catch sustainability in bycatch. Such species should then be the focus of research and management. The authors have recorded at least 411 species from 99 families as bycatch, identifying 15 species with the least likelihood of catch sustainability as well as the 13 with the most likelihood of catch sustainability. This approach was designed to overcome problems such as the high diversity of bycatch in tropical fisheries and the lack of information on individual species. The method is versatile and can also be applied to other fisheries, although the criteria employed may vary.

The present study describes a rapid, innovative method, based on the method developed by Stobutzki et al. (2001), for evaluating the impact of trap fisheries on ornamental species using biological data and the portion of the population caught. The intention is to answer the following two questions. (1) Is the method appropriate for ornamental reef fish? (2) Is the capture of ornamental reef fish as by-catch sustainable? The present study records the occurrence of ornamental fish caught as by-catch and assesses the susceptibility and resilience of fish from the Pomacanthidae and Chaetodontidae families.

## Materials and Methods

## Sampling

The fish recorded here were acquired from the fishing colony of Itamaracá island located on Pilar beach ( $7^{\circ} 45^{\prime} 17.80^{\prime}$ ' $\mathrm{S}-34^{\circ} 49^{\prime} 26.46^{\prime \prime} \mathrm{W}$ ) (Itamaracá, state of Pernambuco, Brazil - Fig. 1) and were caught as bycatch while trap fishing for the spotted goatfish, Pseudupeneus maculatus and parrotfish, Sparisoma spp. This kind of fishing occurs throughout the year and is carried out on alternating days. The boats

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leave Pilar beach at midnight and arrive at Tambaba beach, 46 km away, ( $7^{\circ} 22^{\prime} 2.93^{\prime}{ }^{\prime} \mathrm{S}$ $-34^{\circ} 47^{\prime} 48.51^{\prime}$ 'W) (state of Paraíba) in the early morning. Four boats are employed in this fishery. Each has a fishing effort of 15 to 20 traps and trap mesh varying between 1 and 7 cm . The traps are deployed unbaited next to reefs and hauled 6 hours later. Occasionally, depending on factors such as wind and currents, some traps are left for longer periods and only hauled after 48 hours. The fish are stored for approximately 7 hours in $100-\mathrm{L}$ containers. For the present study, weekly samplings were performed from April to June 2006. The fishermen were asked to bring back all of specimens with ornamental characteristics, which were then bought. In the case of $H$. ciliaris and $P$. paru, this procedure was carried out over a longer period (March 2006 to February 2007), as these two species were the focus of another study.


Figure 1: Location of sampled area.

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Nekton and Aquaculture Laboratory of the Oceanography Department of the Universidade Federal de Pernambuco, where they were identified, measured and photographed.
Analysis of catch sustainability of ornamental reef fish bycatch
Only the most abundant species were analysed, i.e., species from the Pomacanthidae and Chaetodontidae families. Rare species for Brazilian northeastern coast, such as C. ocellatus and P. arcuatus (Thresher 1980; Carvalho Filho 1999) were not surveyed due to the small sample size. Information on the biological characteristics of the selected species was taken from specific publications, such as Robins and Ray (1986); Thresher (1980, 1984); Allen (1998), Hourigan et al. (1989) and Froese and Pauly (2007).

The method proposed to access the sustainability of selected bycatch species was adapted from Stobutzki et al. (2001) and applied based on two scored sets of criteria: (1) relative vulnerability to capture by traps and mortality due to trap fishery; and (2) the recovery capacity of a species after the population is depleted. The criteria were originally developed during a study on the sustainability of all North Australian Prawn Fishery (NPF) prawn-trawl vertebrate bycatch (Stobutzki et al. 2000). These criteria were modified and assigned relative importance weights by the NPF Assessment Group (Milton, 2001). Values ranging 1 to 3 were attributed to each sustainability indicator, for which 1 denotes the highest value for the susceptibility criteria and the lowest for resilience. Depending on the criterion, these values were based on either categorical or continuous data. When no information was available to assign the divisions between values, the range of the data was divided into thirds in order to create categories (Table 1). The rank matrix constructed from these values for each set of criteria are plotted as axes (resilience versus susceptibility) on a graph indicating the species with the greatest catch sustainability. This graph is recommended only if the different species have different values on each axis. According to Stobutzki et al. (2001), when speciesspecific information is unavailable, a species is given the same value as other species within the same family. With criteria for which family members are not similar or for which no family information is available, the rank of 1 is given as a precautionary measure.

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The criteria adopted to analyse species susceptibility (axis 1) to capture and possible mortality due to fishery efforts were adapted from Stobutzki et al. (2001) and are summarised as follows: (1.1) water column position - as traps are deployed on the substrate (Mahon and Hunte, 2001; Garrisson et al. 2004), benthic and demersal species are more susceptible to capture than the pelagic species; (1.2) preferred habitat - species are ranked according to their preference for rocky habitats. This criterion addresses the likelihood that a species habitat overlaps the area in which trap fishery occurs. Coral reef habitats have been historically targeted by trap fisheries (Wolff et al. 1999). Thus, species that live near shore and depend on a specific habitat, such as coral reefs, are highly vulnerable to a possible risk of extinction (Dye et al. 1994; Roberts and Hawkins, 1999); (1.3) day/night catchability - as trap fishery is a daytime operation, species with diurnal habits are more susceptible to capture by traps; (1.4) diet addressing whether eating habits attract species to trap fishery areas. Thus, species that generally feed on benthic or demersal organisms found on reefs are more vulnerable to capture. Invertebrate feeders (mobile and sessile) are the dominant trophic guild in traps deployed in coral reef habitats (Garrison et al. 2004); (1.5) depth range - this trap fishery occurs in areas between 30 and 40 m . According to Wolff et al. (1999), trap fisheries in adjacent coral reef and gorgonian habitats range from 3 to 38 m . Overlap between the depth range of the trap fishery area and that of the preferred habitat will affect the vulnerability of a species to capture more than that of others that live in either deeper or shallower areas. Fish that have a narrow vertical depth range are highly vulnerable to extinction (Dye et al. 1994; Roberts and Hawkins, 1999) (Table 1).

Six criteria adapted from Stobutzki et al. (2001) were employed to analyse species resilience: (2.1) the maturity criterion - if most individuals caught are larger than their size at first maturity, the species has a greater probability of recovering from a declining population; (2.2) maximum size - species that attain large sizes tend to live longer and therefore the resilience of the population is lower than species with smaller body sizes. A slow life history (e.g. late maturity, long reproductive span and large body size) is related to low maximum population growth rates and, consequently, such species are more vulnerable and have less capacity to recover from exploitation (Hutchings 2001; Reynolds et al., 2001, 2002); (2.3) removal rate - species-based quotas established by the Brazilian environmental protection agency (IBAMA) to

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ensure that harvests are maintained at a sustainable level. The ornamental species fishery is highly selective and certain species such as chaetodonthids and pomacanthids are preferred targets. Among those, the species which are rare may be vulnerable to over-exploitation (Wood 2001b); (2.4) reproductive strategy - species capable of dispersion over long distances are less vulnerable to extinction (Dye et al. 1994; Roberts and Hawkins, 1999). Thus, the resilience of R-strategist species is generally higher than that of K-strategist species; (2.5) hermaphroditism - hermaphroditic species, especially protandric species, may be at great risk of extinction, as fisheries select individuals of certain sizes, which has a negative effect on reproduction (the fishing effort is directed at only one sex) (Dye et. al. 1994; Roberts and Hawkins, 1999; Hawkins and Roberts, 2003); (2.6) mortality index - this index was proposed by Sparre and Venema (1992) and Stobutzki et al. (2001). This index can be derived from the length frequency of a species and von Bertalanffy growth parameters. However, such parameters are not available for most bycatch species. Thus, the index can be calculated as follows:

Mortality index (Z): (L max - L mean)/ (L mean - L min)
in which L max is the maximum length recorded in the literature; L mean is the mean length of total number of individuals caught; L min is the minimum length of the individuals in the sample. In the present study, the mortality index range was calculated ( $0.13-0.74$ ) and divided into thirds for the division between ranks (Table 1).

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Table 1: The criteria used to assess the susceptibility of bycatch species to capture and mortality due to traps and their recovery. For each criterion the weighting score and definition of the three ranks is given.

| Criteria | Weighting score | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ |
| :--- | :--- | :--- | :--- | :--- |
| Susceptibility |  |  |  |  |
| Water column position | 3 | Demersal or benthic | Benthopelagic | Pelagic |
| Preferred habitat | 3 | Rocky habitats with gravel and sand | Habitats with soft or muddy bottoms | No fishing habitats |
| Day/night catchability | 2 | Higher catch rate at day | No difference between day and night | Higher catch rate at night |
| Diet | 3 | Feed on demersal or bent. organisms | Feed on benthopelagic organisms | Feed on pelagic organisms |
| Depth range | 1 | Less than 40 m | - | Deeper than 40m |
| Resilience |  |  |  |  |
| Maturity | 3 | Mature individuals $<50 \%$ |  | Mature individuals $>50 \%$ |
| Maximum size | 3 | Max. size $\geq 50 \mathrm{~cm}$ | $16 \mathrm{~cm}<$ Max. size $<50 \mathrm{~cm}$ | Maximum size $\leq 16 \mathrm{~cm}$ |
| Removal rate | 3 | Catch $\geq 3500$ inds/comp/yr | $1000<$ catch $<3500$ inds $/ \mathrm{comp} / \mathrm{yr}$ | Catch $\leq 1000$ inds $/ \mathrm{comp} / \mathrm{yr}$ |
| Reproductive strategy | 2 | Bear live young or brood young | Guard eggs and/or young | Broadcast spawners |
| Hermaphroditism | 1 | Protandric hermaphrodites | Protoginic hermaphrodites | Dioecious |
| Mortality index | 1 | Mortality index $\geq 3.19$ | $0.96<$ mortality index $<3.19$ | Mortality index $\leq 0.96$ |

Caption: bent - benthic; Max - Maximum; inds/comp/yr - individuals/company/year

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## Analysis of criteria

The overall ranks of susceptibility or resilience were calculated according to the equation below:

$$
\mathrm{Si}=\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{wj} \mathrm{Ri} / \sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{wj}
$$

in which Si is the total susceptibility or resilience rank for species i ; wj is the weight for criterion j ; Ri is the rank of species i for criterion j ; and n is the number of criteria for each axis.

## Statistical analysis

Data normality was evaluated using the Kolmogorov-Smirnov test (BioEstat 5.0 software - Instituto de Desenvolvimento Sustentável Mamirauá). The parametric Z test (BioEstat 5.0 software) was used to determine the probability of a captured individual being smaller than size at first maturity and the probability of a captured individual having bred at least once. Correspondence analysis (Multivariate Statistical Package MVSP 3.1 software - Kovach Computing Services) was used to determine and describe the correspondence between species and criteria on a same graph. This multivariate analysis was used only for criteria related to resilience, as values regarding susceptibility did not vary among species. Since the variance of the reproductive strategy criterion was equal to zero, this criterion was not applied in the present analysis.

## Results

Among the fish caught, 19 were recorded as bycatch species and belong to 14 genera and 10 families (Table 2). Of these, $100 \%$ come from reef environments and are used in the aquarium trade and only one species (Equetus lanceolatus) was not authorised for export. A total of 430 individuals were sampled: 147 H . ciliaris, 46 H . tricolor, 200 P. paru and 37 C. striatus. Length frequency distribution by species (Fig. 2 ) revealed a broad length range among the individuals sampled.

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Figure 2: Length distributions for the four analyzed species. P values refers to normality.

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Table 2: Species registered as bycatch, with the respective common names.

| Family | Species | Common name | n |
| :---: | :---: | :---: | :---: |
| Sygnathidae | Hippocampus reidi Ginsburg, 1933 | Longsnout seahorse | 2 |
| Synodontidae | Synodus foetens (Linnaeus, 1766) | Inshore lizardfish | 2 |
| Aulostomidae | Aulostomus maculatus Wheeler, 1955 | Trumpetfish | 1 |
| Sciaenidae | Equetus lanceolatus (Linnaeus, 1758) | Jack-knife fish | 2 |
| Sciaenidae | Pareques acuminatus (Bloch \& Schneider, 1801) | Highhat | 1 |
| Chaetodontidae | Chaetodon ocellatus Bloch 1787 | Spotfin butterflyfish | 2 |
| Chaetodontidae | Chaetodon striatus Linnaeus, 1758 | Banded butterflyfish | 37 |
| Pomacanthidae | Holacanthus ciliaris (Linnaeus, 1758) | Queen angelfish | 147 |
| Pomacanthidae | Holacanthus tricolor (Bloch, 1795) | Rock beauty | 46 |
| Pomacanthidae | Pomacanthus arcuatus (Linnaeus, 1758) | Gray angelfish | 3 |
| Pomacanthidae | Pomacanthus paru (Bloch, 1787) | French angelfish | 200 |
| Labridae | Bodianus rufus (Linnaeus, 1758) | Spanish hogfish | 23 |
| Labridae | Bodianus pulchellus (Poey, 1860) | Spotfin hogfish | 3 |
| Labridae | Halichoeres dimidiatus (Agassiz, 1831) | Brazilian yellowcheek wrasse | 31 |
| Labridae | Halichoeres brasiliensis (Bloch, 1791) | Brazilian wrasse | 10 |
| Monacanthidae | Cantherhines macrocerus (Hollard, 1855) | Whitespotted filefish | 1 |
| Monacanthidae | Stephanolepis hispidus (Linnaeus, 1766) | Planehead filefish | 1 |
| Ostracidae | Lactophrys trigonus (Linnaeus, 1758) | Buffalo trunkfish | 9 |
| Tetraodontidae | Canthigaster figueiredoi Moura \& Castro (2002) | Southern Atlantic sharpnose-puffer | 1 |

All information on susceptibility criteria is species-specific and the four species evaluated in the sustainability analysis obtained the same value (1) for this criterion. Rank resilience ranged from 1.92 to 2.54 ; H. tricolor and P. paru obtained the smallest and the largest values, respectively (Table 3). Based on these results, it can be affirmed that $H$. tricolor has the least catch sustainability, followed by H. ciliaris and C. striatus. P. paru is the most capable of recovering from a population decline.

Mean and smallest lengths for $H$. tricolor and C. striatus individuals were under size at first maturity. There was a $71 \%$ probability of H . tricolor individuals and a $92 \%$ probability of $C$. striatus being caught at sizes smaller than first maturity. Contrarily, the probability of captured individuals being larger than maturity size was $76 \%$ for $H$. ciliaris and $70 \%$ for $P$. paru. H. ciliaris had the highest mortality index $(\mathrm{Z}=3.19)$ and $P$. paru had the lowest $(\mathrm{Z}=0.96)$ (Table 4).

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Table 3: The ranking of the species on the criteria on the resilience axis.

| Resilience |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Species/Weight | $\mathbf{3}$ | $\mathbf{3}$ | $\mathbf{3}$ | $\mathbf{2}$ | $\mathbf{1}$ | $\mathbf{1}$ | Rank |
|  | Maturity | Maximum size | Removal rate | Reproductive strategy | Hermaphroditism | Mortality index |  |
| Holacanthus ciliaris | 3 | 2 | 1 | 3 | 2 | 1 | 2.08 |
| Holacanthus tricolor | 1 | 2 | 2 | 3 | 2 | 2 | 1.92 |
| Pomacanthus paru | 3 | 2 | 2 | 3 | 3 | 3 | 2.54 |
| Chaetodon striatus | 1 | 3 | 3 | 3 | 3 | 2 | 2.46 |

Table 4: The length at first capture, length at maturity, probability of individuals caught are below of the length at maturity, probability of breeding, mean and maximum length (Max. length) of the species and the mortality index ( Z ) of each.

| Species | n | $\mathrm{L}^{\prime}$ <br> $(\mathrm{cm})$ | Lm <br> $(\mathrm{cm})$ | Prob. $\mathrm{L}<\mathrm{Lm}$ <br> $(\mathrm{cm})$ | Prob. of breeding | L mean $\pm$ S. E <br> $(\mathrm{cm})$ | Max. Length <br> $(\mathrm{cm})$ | Z |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H. ciliaris | 147 | 20.88 | 24.3 | $\mathrm{p}=0.24$ | $\mathrm{p}=0.76$ | $26.58 \pm 0.2672$ | $45($ Allen, 1998) | 3.19 |
| H. tricolor | 46 | 11.32 | 19 | $\mathrm{p}=0.71$ | $\mathrm{p}=0.29$ | $17.61 \pm 0.3646$ | 35 (Allen, 1998) | 2.68 |
| P. paru | 200 | 13.44 | 25 | $\mathrm{p}=0.30$ | $\mathrm{p}=0.70$ | $28.30 \pm 0.4510$ | 41 (Cervigón, 1993) | 0.96 |
| C. striatus | 37 | 9.09 | 13.2 | $\mathrm{p}=0.92$ | $\mathrm{p}=0.07$ | $11.26 \pm 0.2257$ | 16 (Lieske and Myers, 1994) | 2.17 |

Caption: n - number of individuals, L' - length at first capture, Lm - length at maturity, Prob - probability, Max. Length - maximum length, Z - mortality index.

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The correspondence analysis for resilience revealed that $H$. tricolor and $C$. striatus are linked to the removal index. H. ciliaris and P. paru are associated through maturity criteria. Chaetodon striatus and P. paru are grouped with maximum size and mortality index criteria, respectively. Negative relationships were determined for $H$. ciliaris and the removal rate and mortality index; H. tricolor and C. striatus with maturity criteria; and $P$. paru with maximum size. The percentage of the cumulative variation for the two axes was 99.53\% (Fig. 3).


Figure 3: Correspondence analysis showing the relationship between species and criteria used to evaluate the recovery capacity.

Caption: Hol. cil. - Holacanthus ciliaris, Hol. tri. - Holacanthus tricolor, Cha. str. - Chaetodon striatus, Pom. par. - Pomacanthus paru, Max. Size Maximum size.

## Discussion

The present study demonstrates that trap fishery is not selective. The catching of ornamental fish occurs frequently and likely causes considerable impact. Ornamental species are already considered seriously endangered due to fishery efforts (Cheung et al. 2007). Individuals caught are not landed and are usually returned to the sea (many still alive, according to the fishermen). Despite this, the survival of these individuals is

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doubtful, as the traps are hauled quickly to surface and problems related to decompression have often been reported (Burns and Restrepo 2002).

The method applied in the present study was developed with the purpose of classifying ornamental fish species according to possible risk of extinction due to being captured as bycatch. This analysis is influenced by the length range and proportion of young and immature individuals sampled, as criteria that are directly related to specimen size are employed, such as length at first maturity and mortality index. Different mesh sizes are used in this fishery activity, which may have contributed toward the broad length range among the individuals sampled. Due to the small sample size for $H$. tricolor and $C$. striatus, the length range of the specimens caught may not be representative. Thus, for these species, the analysis must be considered only for demonstration (exploratory) purposes, even though there was a trend toward normality in the length distribution data. The present study is the first to test a method with such goals directed at trap fisheries and using criteria based on life history.

Specific biological information is optimised when well-defined criteria are applied, including characteristics that affect species sensitivity or risk of extinction (Dye et al. 1994; Roberts and Hawkins 1999; Stobutzki et al. 2001). Stobutzki et al. (2001) apply the value 1 in the matrix when there is no specific information on certain criterion. In the present study, all biological information was species-specific. Although the analysis presented is subjective, this may be the only one available to evaluate and monitor multi-specific fisheries (Dulvy et al. 2003), especially newly developed fisheries.

## Susceptibility to capture by traps

Species caught by a given equipment share similar characteristics, such as habitat, diet and period of activity. Thus, reef fish are considered highly susceptible to trap fisheries. Pomacanthidae are widely distributed in depths ranging from 1 to 100 m (Allen 1998; Michael 2004; Froese and Pauly 2007), whereas Chaetodontidae occur between 3 to 55 m (Allen 1998; Robins and Ray 1986; Froese and Pauly 2007). The former feed on sponges, zoanthids, tunicates, hydroids, bryozoans and algae (Randall 1967; Allen 1998; Michael 2004). Chaetodontidae eat worms, coral polyps and mollusc eggs (Allen 1998). The diet and period of activity of these fish favour their capture, as they only feed during the day (Starck and Davis 1966) and the organisms they eat are

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sessile, which are generally encrusted on reefs. Dependence on a particularly susceptible habitat (e.g. coral reefs), either alone or combined with overfishing, leads to considerable captures of bycatch species and makes these species all the more vulnerable (Reynolds and Jennings 2000).

## Resilience

Species with late sexual maturity are highly vulnerable to the risk of extinction and consequently have a poor recovery capability (Dye et al. 1994; Roberts and Hawkins 1999; Sadovy 2005). The correspondence analysis reveals the clustering of $H$. ciliaris and $P$. paru with the maturity criterion, due to the fact that more than a half of the sampled individuals had bred at least once. The opposite was found for H. tricolor and C. striatus, for which respectively $70 \%$ and $92 \%$ of individuals sampled were immature. Myers and Worm (2005) state that the risk of extinction is very high if recruits are being captured and low when fish are caught after first sexual maturity. Thus, the maturity criterion had a positive influence on the classification of $H$. ciliaris and $P$. paru in relation to resilience.

Large body size is often correlated with other vulnerability factors, such as late maturity, and substantially increases the possibility of being caught in traps (Reynolds and Jennings 2000; Reynolds et al. 2002, Cheung et al. 2007). Body size is a useful measure in evaluating species resilience due to its relationship with the intrinsic rate of increase of a population. Thus, it can be applied to populations and species for which minimal biological data are available (Denney et al. 2002). In the Pomacanthidae family, the genera Holacanthus and Pomacanthus have the largest lengths (Bellwood 2004). Among the analysed fish, P. paru was the second largest, but exhibited the greatest resilience. This can be explained by the fact that most individuals caught were fit for reproduction and the species had the lowest mortality rate.

The demand for marine ornamental fish increased in the 1980s and 1990s (Chan and Sadovy, 1998). Concerns have been raised regarding its negative effect on reef fish and coral habitats, as nearly all ornamental marine fish are taken from the wild (Andrew 1990; Wood 2001a). The potential for over-exploitation from the aquarium trade is high due to the high selectivity of this activity and the large number of fish collected (Wood 2001a). It is estimated that most commercialised ornamental fish are juveniles and less than 10 cm in standard length (Chan and Sadovy, 1998). Pomacanthidae and

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Chaetodontidae are often the most important families for export in terms of number and value (Wood 2001a). In the Brazilian aquarium trade, these two families are among the most representative in species richness (Gasparini et al. 2005). In the state of Ceará (one of the main centres of the Brazilian ornamental fish trade), H. ciliaris, P. paru, Hippocampus erectus, Pomacanthus arcuatus and Holacanthus tricolor made up 50\% of the total trade between 1995 and 2000 (Monteiro Neto et al. 2003). Among the species evaluated, H. ciliaris is the most harvested by the Brazilian aquarium trade (IBAMA - Federal Act 56/04). The correspondence analysis corroborates this statement, revealing a negative relationship between $H$. ciliaris and removal rate.

Regarding reproductive strategy, all species evaluated are broadcast spawners (Thresher 1980; 1984). Therefore, they are less vulnerable to extinction due to their widespread distribution and the high re-colonisation potential of depleted populations (Malakoff 1997; McKinney 1997). However, larval behaviour, spawning events and local oceanography processes can influence larval dispersion by increasing local retention (Cowen et al. 2006; Rocha et al. 2007). Hawkins et al. (2000) state that, despite reef fish being broadcast spawners, their geographic distribution is small; $24 \%$ are restricted to less than $800,000 \mathrm{~km}^{2}$ and $9 \%$ are restricted to less than $50,000 \mathrm{~km}^{2}$. Based on these statements, it is possible to infer that being a broadcast spawner does not ensure low vulnerability to extinction.

Hermaphroditic species are likely to be very sensitive to over-fishing, as individuals need to attain a certain length for the gender change to occur (Francis 1992). If fishing affects the growth of the fish such that sexual inversion does not occur, this could result in a non-reproductive population and even cause the species to disappear in intensely exploited areas (Hawkins and Roberts 2003). Among the species analysed in the present study, those from the Holacanthus genus are protogynous hermaphrodites (Thresher 1980; 1984; Allen 1998; Moyer et al. 2003). These species are heavily exploited by the aquarium trade, in which most individuals collected are small in size (Chan and Sadovy 1998) and probably belong to the same sex (i.e., female). H. tricolor and $H$. ciliaris revealed the lowest recovery capacity. However, according to the correspondence analysis, the hermaphroditism criterion had no influence over their classification regarding resilience. This may be explained by the absence of protandric

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species in the analysis, as such species are more sensitive than protogynous species (Sadovy and Shapiro1987; Hawkins and Roberts 2003).

Throughout the life cycle, individuals are exposed to different types of environmental pressure. The natural mortality rate decreases as the fish grows and becomes less vulnerable to predators. The mortality coefficient used in the present study considered data on maximum and mean catch length (Beverton and Holt 1956). H. ciliaris had the highest mortality index among the species analysed due to the mean catch size, which was below that found in the literature (Allen 1998). This coefficient along with the criterion related to the removal rate - had a negative influence on the resilience of this species.

Resilience ranks were different for the four species analysed, even for those belonging to the same family. Stobutzki et al. (2001) state that the catch of a species is not sustainable if it has both high resilience and susceptibility. The results obtained for C. striatus and $P$. paru are in agree with this statement, as these species revealed considerable resilience, but were highly susceptible according to the ecological information (such as diet, preferred habitat and depth range). This suggests that catching these species is not a sustainable practice.

The method employed in the present study (susceptibility and resilience criteria) is efficient for evaluating the impact of recently-formed fisheries with few available data that occur in areas with high species richness (Dulvy et al. 2003, 2004), such as reef environments. However, in order to incorporate the results of this study to fishery management measures, the vulnerability analysis (VA) can be utilised as a component of a risk analysis when only qualitative data is available and researchers lack an understanding of cause/effect relationships (Walker et al. 2002; McFadden 2007).

Most fishing equipment is not selective and many fish are caught as bycatch even when there is only one target species. These species are highly affected by fishery efforts, as bycatch will continue to be fished as long as it remains viable to catch the target species. Trap fisheries targeting reef fish have recently developed in Brazil and are on the rise in the north-eastern region. Regulatory agencies often take a long time to react and severe declines in non-target species go unperceived. Thus, little is known regarding the impact of this activity and such lack of information hinders regulatory efforts. The method presented here is an appropriate, practical tool for fishery

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management and the assessment of catch sustainability in multi-species fisheries on which there is limited available data. It can also be employed to determine which species are at a possible risk of extinction due to bycatch. Furthermore, it is important to consider that to reduce the extinction threat posed on those species, a socio-economic vulnerability analysis is required in order to develop the appropriate institutional framework/outreach program to the fishers necessary to address this ecological challenge.

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## References

Allen, G. R. (1998). Introducing angelfish. In 'A Guide to Angelfish and Butterflyfish', pp. 8 - 12. (Mergus Publishers:Melle, Germany).

Andrew, C. (1990). The ornamental fish trade and conservation. Journal of Fish Biology 37, 53-59.

Araújo, M. E. and Albuquerque Filho, A. C. (2005). Biologia das principais espécies de peixes ornamentais marinhos do Brasil: uma revisão bibliográfica e documental. Boletim Técnico Científico do CEPENE 13, 109-154.

Bellwood, D. R., van Herwerden, L. and Konow, N. (2004). Evolution and biogeography of marine angelfish (Pisces: Pomacanthidae). Molecular Phylogenetics and Evolution 33, 140-155.
Beverton, R. J. H. and Holt, S. J. (1956). A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapp. P. -v. Réun. CIEM 140, $67-83$.

Burns, K. M. and Restrepo, V. (2002). Survival of reef fish after rapid depressurization: field and laboratory studies. American Fisheries Society Symposium 30, 148-151.
Carvalho-Filho, A. (1999). As espécies e suas famílias. In: Peixes: Costa Brasileira, pp. 40-283. (Editora Melro: São Paulo, SP).

Catch sustainability of ornamental fish bycatch...

Casey, J. M. and Myers, R. A. (1998). Near extinction of a large, widely distributed fish. Science 281, 690-691.

Cervigón, F. (1993). Pomacanthidae. In 'Los Peces Marinos de Venezuela’, pp. 339 346. (Fundación Científica Los Roques: Caracas, Venezuela).

Chan, T. T. C. and Sadovy, Y. (1998). Profile of the marine aquarium fish trade in Hong Kong. Aquarium Sciences and Conservation 2, 197-213.
Cheung, W. W. L., Watson, R., Morato, T, Pitcher, T. J. and Pauly, D. (2007). Intrinsic vulnerability in the global fish catch. Marine Ecology Progress Series 333, 1 - 12.

Cowen, R. K., Paris, C. B. and Srinivasan, A. (2006). Scaling of connectivity in marine populations. Science 311, 522-527
Dalzell, P., Adams, T. J. H. and Polunin, N. V. C. (1996) Coastal fisheries in the Pacific Islands. Oceanography and Marine Biology: an annual review 34, 395-531.

Denney, N. H., Jennings, S. and Reynolds, J. D. (2002). Life-history correlates of maximum population growth rates in marine fish. Proceedings of Royal Society London 269, 2229 - 2237.

Dulvy, N. K., Ellis, J. R., Goodwin, N. B., Grant, A., Reynolds, J. D. and Jennings, S. (2004). Methods of assessing extinction risk in marine fish. Fish and Fisheries 5, 255-276.

Dulvy, N. K., Sadovy, Y. and Reynolds, J. D. (2003). Extinction vulnerability in marine populations. Fish and Fisheries 4, 25-64.

Dye, A. H., Schleyer, M. H., Lambert, G. and Lasiak, T. A. (1994). Biological option for the management of the exploitation of intertidal and subtidal resources. In ‘Rocky Shores: Exploitation in Chile and South Africa'. (Ed.W.R. Siegfried) pp. 131-154. (Springer-Verlag).

Eayrs, S. (2007). Guía para Reducir la Captura de Fauna Incidental (Bycatch) en las Pesquerías por Arrastre de Camarón Tropical. FAO, Rome.

Francis, R. C. (1992). Sexual lability in teleosts: developmental factors. Quartely Review of Biology 67, 1-18.

Froese, R. and Pauly, D. (2007). FishBase. Available at http:// www.fishbase.org. [Accessed 29 October 2007]

Catch sustainability of ornamental fish bycatch...

Garrison, V. H., Rogers, C. S. and Beets, J. (1998). Of reef fish, overfishing and in situ observations of fish traps in St. John, U. S. Virgin Islands. Revista de Biologia Tropical 46, 41 - 59.

Gasparini, J. L., Floeter, S. R., Ferreira, C. E. L. and Sazima, I. (2005). Marine ornamental trade in Brazil. Biodiversity and Conservation 14, 2883 - 2899.

Hawkins, J. P. and Roberts, C. M. (2003). Effects of fishing on sex-changing Caribbean parrotfish. Biological Conservation 115, 213-226.

Hawkins, J. P., Roberts, C. M. and Clark, V. (2000). The threatened status of restrictedrange coral reef fish species. Animal Conservation 3, 81-88.

Hourigan, T. F., Stanton, F. G., Motta, P. J., Kelley, C. D. and Carlson, B. (1989). The feeding ecology of three species of Caribbean angelfish (family Pomacanthidae). Environmental Biology of Fish 24, 105-116.

Hutchings, J. A. (2001). Conservation biology of marine fish: perceptions and caveats regarding assignment of extinction risk. Canadian Journal of Aquatic Sciences 58, 108-121.

Kelleher, K. (2005). Discards in the world's marine fisheries. An update. FAO Fisheries Technical Paper. $\mathbf{N}^{\mathbf{0}}$ 470. FAO: Rome. 131p.

Lieske, E. and Myers, R. (1994). Spadefish and Butterflyfish, In ‘Collins Pocket Guide. Coral reef fish. Indo-Pacific and Caribbean including the Red Sea'. pp. 161-162 (Princeton University Press: Princeton, NJ).

Mahon, R. and Hunte, W. (2001). Trap mesh selectivity and the management of reef fish. Fish and Fisheries 2001, 356-375.

Malakoff, D. (1997). Extinction on the high seas. Science 277, 486 - 488.
McFadden, L. (2007). Vulnerability analysis in environmental management: widening and deepening its approach. Environmental Conservation 34, 195 - 204.

McKinney, M. L. (1997). Extinction vulnerability and selectivity: combining ecological and paleontological views. Annual Review of Ecology and Systematics 28, 495 516.

Michael, S. W. (2004). Family Pomacanthidae/Angelfish. In 'Angelfish and Butterflyfish' pp. 210-321 (T. F. H Publications: Neptune City).

Catch sustainability of ornamental fish bycatch...

Milton, D. A. (2001) Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's Northern Prawn Fishery. Biological Conservation 101, 281 - 290.
Monteiro Neto, C., Cunha, F. E. A., Nottingham, M. C, Araújo, M. E, Rosa, I. L. and Barros, G. M. L. (2003). Analysis of the marine ornamental fish trade at Ceará State, northeast Brazil. Biodiversity and Conservation 12, 1287-1295.

Moyer, J. T., Thresher, R. E. and Colin, P. L. (1983). Courtship, spawning and inferred social organization of American angelfish (genera Pomacanthus, Holacanthus and Centropyge: Pomacanthidae). Environmental Biology of Fish 9, 25-39.

Myers, R. A. and Worm, B. (2005). Extinction, survival or recovery of large predatory fish. Philosophical Transactions of the Royal Society 360, 13 - 20.

Nottingham, M. C., Cunha, F. E. and Monteiro Neto, C. (2000). Captura de peixes ornamentais marinhos no Ceará. Arquivos Ciências do Mar 33, 113-118.

Pope, J. G., MacDonald, D. S., Dann, N., Reynolds, J. D. and Jennings, S. (2000). Gauging the impact of fishing mortality on nontarget species. ICES Journal of Marine Science 57, 689-696.

Reynolds, J. D. and Jennings, S. (2000). The role of animal behavior in marine conservation. In 'Behavior and Conservation’ (Eds. L. M. Gosling and W. J. Shuterland.) pp. 147 - 168. (Cambridge University Press: Cambridge, UK)

Reynolds, J. D., Jennings, S. and Dulvy, N. K. (2001). Life histories of fish and population responses to exploitation exploitation. In 'Conservation of Exploited Species' (Eds. J. D. Reynolds, G. M. Mace, K. H. Redford and J. G. Robinson.) pp. 147-168. (Cambridge University Press: Cambridge, UK.).

Reynolds, J. D., Dulvy, N. K. and Roberts, C. M. (2002). Exploitation and other threats to fish conservation. In 'Fish and Fisheries Handbook' (Eds. P. J. B. Hart and J. D Reynolds.) pp. 319 - 341. (Blackwell Science: Oxford).

Ribeiro, F. P. (2004). Composição da biocenose e abundância relativa de peixes capturados com covos nos Estados do Rio Grande do Norte e Pernambuco. Boletim Técnico Científico do CEPENE 12, 113 - 128.
Rocha, L. A., Craig, M. T. and Bowen B. W. (2007). Phylogeography and the conservation of coral reef fish. Coral reefs Online First.

Catch sustainability of ornamental fish bycatch...

Roberts, C. M. and Hawkins, J. P. (1999). Extinction risk in the sea. Trends in Ecology and Evolution 14, 241-246.

Robins, C. R. and Ray, C. G. (1986). Butterflyfish: Family Chaetodonidae. In 'A field Guide to Atlantic Coast Fish of North America’ pp. 192 - 194. (Houghton Mifflin Company: New York).
Sadovy, Y. and Shapiro, D. Y. (1987). Criteria for the diagnosis of hermaphroditism in fishes. Copeia 1, 136-156.
Sadovy, Y. (2005). Trouble on the reef: the imperative for managing vulnerable and valuable fisheries. Fish and Fisheries 6,167-185.

Sparre, P. and Venema, S.C. (1992) Introduction to tropical fish stock assessment, part 1. FAO Fisheries Technical Paper. $\mathbf{N}^{\mathbf{0}} \mathbf{3 0 6}$. FAO: Rome. 376 p.

Starck, W. A. I. and Davis, W. P. (1966). Night habits of fish of Alligator Reef, Florida. Ichthyologica 38, 313-356.
Stobutzki, I., Blaber, S., Brewer, D., Fry, G., Heales, D., et al. (2000). Ecological sustainability of bycatch and biodiversity in prawn trawl fisheries. Fisheries Research and Development Coporation, Final Report Project 96/257, Australia.
Swingle, W. E., Dammann, A. E. and Yntema, A. N. (1970). Survey of the commercial fishery of the Virgin Islands of the United States. Proceedings of the Gulf and Caribbean Fisheries Institute 20, 110-121.

Stobutzki, I., Miller, M. and Brewer, D. (2001). Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch. Environmental Conservation 28, 167-181.

Thresher, R. E. (1980). Angelfish. In 'Reef fish: Behavior and Ecology on the Reef and in the Aquarium' pp $37-46$ (The Palmetto Publishing Company: St Petersburg, Fl)

Thresher, R. E. (1984). Angelfish (Pomacanthidae). In 'Reproduction in Reef Fish' pp. 244 - 261. (T. F. H. Publications: Neptune City).

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., Peterson, G. D. and Pritchard, R. (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. Conservation Ecology 6:14.

Catch sustainability of ornamental fish bycatch...

Wolff, N., Grober-Dunsmore, R., Rogers, C. S., and Beets, J. (1999). Management implications of fish trap effectiveness in adjacent coral reef and gorgonian habitats. Environmental Biology of Fish 55, 81-90.
Wood, E. M. (2001a). Collection of coral reef fish for aquaria: global trade, conservation issues and management strategies. Marine Conservation Society, Ross-on-Wye, UK.
Wood, E. M. (2001b). Global Advances in Conservation and Management of Marine Ornamental Resources. Aquarium Science and Conservation 3, 65-77.

## Considerações finais

O conhecimento do ciclo de vida de espécies como Pomacanthus paru, que são extraídas diretamente dos recifes para o aquarismo, é fundamental para a sua preservação. Desde o ano 2000, esta espécie vem sendo classificada como a segunda mais exportada pelo Brasil, principalmente pelo Estado do Ceará. Nas últimas reuniões técnicas sobre a exploração de peixes ornamentais marinhos, promovidas pelo IBAMA, foi enfatizada a carência de pesquisas sobre a biologia e a dinâmica populacional das principais espécies exportadas (e.g. Holacanthus ciliaris e Pomacanthus paru).

As considerações aqui apresentadas sobre a diversidade genética dos peixes anjo representam um primeiro passo para se compreender as estruturas populacionais de espécies irmãs e simpátricas, como P. paru e P. arcuatus, embora com histórias evolutivas diferentes. Estudos complementares sobre assentamento larval, características fisiológicas e ações antrópicas dirigidas a essas populações são necessários para inferir sobre essa dinâmica.

As pesquisas relacionadas à biologia reprodutiva indicaram que P. paru é gonocorística e os dados de reprodução, idade e crescimento forneceram informações importantes sobre sua biologia populacional. Algumas hipóteses, como a preferência de habitat entre os sexos, uma maior susceptibilidade de captura das fêmeas por meio das armadilhas e a migração das fêmeas no período reprodutivo para a área de pesca, podem explicar a prevalência de fêmeas na estrutura populacional de Pomacanthus paru. Entretanto, mais pesquisas serão necessárias para responder esta questão.

Os resultados mostraram também que é possível obter estimativas de crescimento para espécies tropicais baseadas em métodos convencionais para determinação de idade. Os dados obtidos nos trabalhos de biologia reprodutiva e idade e crescimento deverão ser utilizados no manejo de P. paru. Algumas medidas de manejo, relacionadas ao aquarismo, já são aplicadas em P. paru. Nos Estados Unidos, o ordenamento da pesca desta espécie para fins ornamentais é realizado por meio da regulamentação de tamanho. No Brasil, o ordenamento é

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feito com cotas de exportação específicas. Estas regulamentações são fundamentais e ajudam na conservação dos estoques e na prevenção contra a sobrexploração. Entretanto, essas medidas foram tomadas sem nenhum conhecimento dos parâmetros populacionais da espécie, como crescimento, longevidade, idade e tamanho de primeira maturação sexual. Esses parâmetros são requisitos mínimos para um manejo pesqueiro efetivo de uma determinada espécie. Diante do exposto, o manejo de P. paru deve incluir medidas baseadas nos parâmetros populacionais aqui estabelecidos, antes que mais restrições sejam impostas. Entretanto, esses parâmetros aqui estabelecidos não se adequam ao manejo das espécies utilizadas no aquarismo, pois a maioria dos indivíduos comercializados é juvenil e inferior a 10 cm de comprimento padrão. Desta forma, sugere-se que as medidas conservacionistas estejam relacionadas a dados quantitativos (captura) por área e criação de áreas de proteção ambiental.

Somada à pressão pesqueira sofrida por esta espécie através do aquarismo, P . paru é constantemente capturada como bycatch em armadilhas de pesca no nordeste do Brasil. Nesta pescaria, mais de $70 \%$ dos indivíduos capturados estavam aptos para a reprodução. É possível que essa espécie sofra pressão pesqueira em todas as faixas de comprimento, uma vez que indivíduos menores que 10 cm são comumente utilizados no aquarismo e aqueles com comprimento entre 15 e 40 cm são frequentemente pescados em armadilhas. A constante captura de indivíduos de maior porte representa um possível risco ao recrutamento para o estoque reprodutivo.

No caso da pesca com armadilhas, não há nenhum tipo de regulamentação para esta atividade. 0 manejo desta atividade é difícil, por ser considerada multi-específica e com impacto desconhecido. A maioria das artes de pesca não é seletiva e muitos peixes são capturados como bycatch, mesmo quando há apenas uma espécie alvo. Esses peixes são altamente afetados, pois enquanto for viável capturar a espécie alvo, o bycatch continuará a ser pescado.

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A metodologia estabelecida nesta tese é uma ferramenta prática e apropriada para o manejo pesqueiro e avaliação da sustentabilidade da pesca de espécies que são capturados em pescarias multi-específicas e com poucos dados disponíveis sobre o impacto da atividade. Este método também pode ser empregado para determinar quais as espécies estão em um possível risco de extinção devido ao bycatch. Além disso, faz-se necessária uma análise de vulnerabilidade sócio-econômica a fim de desenvolver um programa institucional apropriado para os pescadores, no intuito de resolver essa problemática ecológica.

## APÊNDICE

# A rapid new method for assessing sustainability of ornamental fish by-catch from coral reefs 

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#### Abstract

The ornamental fish trade has considerable potential for damaging reef environments. Nearly 120 species are currently harvested in the Brazilian trade and little attention has been paid to the effects of the accidental catch of these species. Records of ornamental fish by-catch and the susceptibility and resilience of species from the major Brazilian families in the aquarium trade were examined to test a method and determine the sustainability of these catches. Each species was assessed based on two groups of criteria: (1) relative vulnerability to capture; and (2) population resilience to mortality due to fishing efforts. Each species was also ranked (1-3) for criteria regarding ecology, biology, catchability, numbers of individuals exported by aquarium companies and mortality index. These criteria were then weighted and each species rank in the two groups of criteria was plotted. Nineteen species from 10 families were recorded. The species least likely to have sustainable catch rates included Holacanthus tricolor, H. ciliaris, Chaetodon striatus and Pomacanthus paru. This approach is a useful alternative for management efforts and the assessment of catch sustainability in newly developed multi-species fisheries with limited available data, which occur in areas of high species richness such as reefs.


Additional keywords: aquarium, Chaetodontidae, fishery, Pomacanthidae, resilience, susceptibility, trap.

## Introduction

Species classified as by-catch (Eayrs 2007) are caught in fisheries that target other groups and are then either used or discarded. It is estimated that 7.3 million tonnes of fish were discarded globally in commercial fisheries between 1995 and 2005 (Kelleher 2005). This is equivalent to $8 \%$ of worldwide marine fish production (Eayrs 2007). The global effect of fisheries on by-catch species is poorly known, although some studies have documented ecological changes at the species level (Casey and Myers 1998; Pope et al. 2000). Even less attention has been paid to accidental catches affecting reef fish, including ornamental species.

Beauty and perfect patterns on ornamental reef fish are requirements imposed by the international aquarium trade (Araújo and Albuquerque Filho 2005), which is one of the world's largest industries. The import value worldwide of marine fish and invertebrates is estimated to be between US $\$ 24$ and 40 million annually (Wood 2001a). Nearly 120 species are currently harvested in the Brazilian aquarium trade (Monteiro Neto et al. 2003). Most belong to the family Pomacanthidae (Araújo and Albuquerque Filho 2005) and species of the Chaetodontidae are among the most exported (Monteiro Neto et al. 2003; Nottingham et al. 2000). Although other fisheries that use traps have an effect on ornamental marine fish stocks (through bycatch), these stocks have only been managed through a Federal Act (56/04) established in 2004 by the Brazilian environmental protection agency (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA), which monitors
the ornamental fish trade through export quotas. The purpose of this Federal Act is to administer this activity through the establishment of export quotas.

Traps are the predominant gear employed to capture reef fish in the Caribbean (Swingle et al. 1970; Garrison et al. 1998) as well as other places in the world (e.g. Arabian Gulf, Seychelles, Papua New Guinea) (Dalzell et al. 1996) and are responsible for the decline of many reef species which are fishery targets (Wolff et al. 1999). Among the organisms caught by these devices, the most frequently caught ornamental fish belong to the following genera: Acanthurus, Chaetodon, Bodianus, Holacanthus and Pomacanthus (Garrison et al. 1998; Wolff et al. 1999). In Brazil, trap fisheries targeting reef fish have been on the rise in the last 10 years (Ribeiro 2004). The target species of these fisheries belong to the genera Acanthurus, Cephalopholis, Lutjanus, Pseudupeneus and Sparisoma (Ribeiro 2004). Because by-catch species, including ornamental species, are returned to the sea and not recorded, there are no data or regulations available about the actual catch of ornamental species.

Owing to the increasing pressure to manage the impact of fisheries on non-target species and the uncertainty of how this is to be done, Stobutzki et al. (2001) developed a broad method using qualitative measures of the biological and ecological characteristics of species to rank vulnerability to a known threat. Stobutzki et al. (2001) examined the impact of trawling on the catch sustainability of teleost by-catch species, identifying the species with the least likelihood of catch sustainability in by-catch. They argued that such species should then be the focus
of research and management. Stobutzki et al. (2001) recorded at least 411 species from 99 families as by-catch, identifying 15 species with the least likelihood of catch sustainability as well as the 13 with the most likelihood of catch sustainability. This approach was designed to overcome problems such as the high diversity of by-catch in tropical fisheries and the lack of information on individual species. The method is versatile and can also be applied to other fisheries, although the criteria employed may vary

The present study describes a rapid, innovative method, based on the method developed by Stobutzki et al. (2001), for evaluating the impact of trap fisheries on ornamental species using biological data and the portion of the population caught. The intention is to answer the following two questions. (1) Is the method appropriate for ornamental reef fish? (2) Is the capture of ornamental reef fish as by-catch sustainable? The present study records the occurrence of ornamental fish caught as by-catch and assesses the susceptibility and resilience of fish from the Pomacanthidae and Chaetodontidae families.

## Materials and methods

## Sampling

The fish were acquired from the fishing colony of Itamaracá island located on Pilar Beach ( $7^{\circ} 45^{\prime} 17.80^{\prime \prime} \mathrm{S}, 34^{\circ} 49^{\prime} 26.46^{\prime \prime} \mathrm{W}$ ) (Itamaracá, Pernambuco, Brazil - Fig. 1) and were caught as bycatch while trap fishing for the spotted goatfish, Pseudupeneus maculatus and parrotfish, Sparisoma spp. This kind of fishing occurs throughout the year and is carried out on alternating days. The boats leave Pilar Beach at midnight and arrive at Tambaba Beach, 46 km away ( $7^{\circ} 22^{\prime} 2.93^{\prime \prime} \mathrm{S}, 34^{\circ} 47^{\prime} 48.51^{\prime \prime} \mathrm{W}$ ) (Paraíba, Brazil) in the early morning. Four boats are employed in this fishery. Each has a fishing effort of 15 to 20 traps and trap mesh varying between 1 and 7 cm . The traps are deployed unbaited next to reefs and hauled 6 h later. Occasionally, depending on factors such as wind and currents, some traps are left for longer periods and only hauled after 48 h . The fish are stored for $\sim 7 \mathrm{~h}$ in $100-\mathrm{L}$ containers. For the present study, weekly samplings were performed from April to June 2006. The fishermen were asked to bring back all specimens with ornamental characteristics, which were then bought. In the case of Holacanthus ciliaris and Pomacanthus paru, this procedure was carried out over a longer period (March 2006 to February 2007), as these two species were the focus of a concurrent study.

The sampled fish were placed in polystyrene chests with ice and taken to the Nekton and Aquaculture Laboratory of the Oceanography Department of the Universidade Federal de Pernambuco, where they were identified, measured and photographed.

## Analysis of catch sustainability of ornamental reef fish by-catch

Only the most abundant species were analysed, i.e. species from the Pomacanthidae and Chaetodontidae. Rare species for Brazil, such as Chaetodon ocellatus and Pomacanthus arcuatus (Thresher 1980; Carvalho Filho 1999) were not surveyed owing to the small sample size. Information on the biological characteristics of the selected species was taken from published literature including Robins and Ray (1986), Thresher (1980
1984), Allen (1998), Hourigan et al. (1989) and Froese and Pauly (2007).

The method proposed to assess the sustainability of selected by-catch species was adapted from Stobutzki et al. (2001) and applied based on two scored sets of criteria: (1) relative vulnerability to capture by traps and mortality due to trap fishery; and (2) the recovery capacity of a species after the population is depleted. The criteria were originally developed during a study on the sustainability of all North Australian Prawn Fishery (NPF) prawn-trawl vertebrate by-catch (Stobutzki et al. 2000). These criteria were modified and assigned relative importance weights by the NPF Assessment Group (Milton 2001). Values ranging from 1 to 3 were attributed to each sustainability indicator, for which 1 denotes the highest value for the susceptibility criteria and the lowest for resilience. Depending on the criterion, these values were based on either categorical or continuous data. When no information was available to assign the divisions between values, the range of the data was divided into thirds to create categories (Table 1). The rank matrix constructed from these values for each set of criteria are plotted as axes (resilience versus susceptibility) on a graph indicating the species with the greatest catch sustainability. This graph is recommended only if the different species have different values on each axis. According to Stobutzki et al. (2001), when species-specific information is unavailable, a species is given the same value as other species within the same family. With criteria for which family members are not similar or for which no family information is available, the rank of 1 is given as a precautionary measure.

The criteria adopted to analyse species susceptibility (axis 1) to capture and possible mortality due to fishery efforts were adapted from Stobutzki et al. (2001) and are summarised as follows. (1.1) Water column position - as traps are deployed on the substrate (Mahon and Hunte 2001; Garrison et al. 2004), benthic and demersal species are more susceptible to capture than pelagic species. (1.2) Preferred habitat - species are ranked according to their preference for rocky habitats. This criterion addresses the likelihood that a species habitat overlaps the area in which a trap fishery occurs. Coral reef habitats have been historically targeted by trap fisheries (Wolff et al. 1999). Thus species that live near shore and depend on a specific habitat, such as coral reefs, are highly vulnerable to a possible risk of extinction (Dye et al. 1994; Roberts and Hawkins 1999) (1.3) Day/night catchability - because trap fishery is a daytime operation, species with diurnal habits are more susceptible to capture by traps. (1.4) Diet - whether eating habits attract species to trap fishery areas. Thus, species that generally feed on benthic or demersal organisms found on reefs are more vulnerable to capture. Invertebrate feeders (mobile and sessile) are the dominant trophic guild in traps deployed in coral reef habitats (Garrison et al. 2004). (1.5) Depth range - the trap fishery that we studied occurs in depths between 30 and 40 m . According to Wolff et al. (1999), trap fisheries in adjacent coral reef and gorgonian habitats range from 3 to 38 m . Overlap between the depth range of the trap fishery area and that of the preferred habitat will affect the vulnerability of a species to capture more than that of others that live in either deeper or shallower areas Fish that have a narrow vertical depth range are highly vulnerable to extinction (Dye et al. 1994; Roberts and Hawkins 1999) (Table 1).


Fig. 1. Location of sampled area.

Six criteria adapted from Stobutzki et al. (2001) were employed to analyse species resilience. (2.1) Maturity - if most individuals caught are larger than their size at first maturity, the species has a greater probability of recovering from a declining population. (2.2) Maximum size - species that attain large sizes tend to live longer and therefore the resilience of the population is lower than species with smaller body sizes. A slow life history (e.g. late maturity, long reproductive span and large body size) is related to low maximum population growth
rates and, consequently, such species are more vulnerable and have less capacity to recover from exploitation (Hutchings 2001; Reynolds et al. 2001, 2002). (2.3) Removal rate - speciesbased quotas established by IBAMA to ensure that harvests are maintained at a sustainable level. The ornamental species fishery is highly selective and certain species, such as chaetodontids and pomacanthids, are preferred targets. Among those, the species that are rare may be vulnerable to over-exploitation (Wood 2001b). (2.4) Reproductive strategy - species capable

Table 1. The criteria used to assess the susceptibility of by-catch species to capture and mortality due to traps and their recovery For each criterion the weighting score and definition of the three ranks is given

| Criteria | Weighting score | 1 | 2 | 3 |
| :---: | :---: | :---: | :---: | :---: |
| Susceptibility |  |  |  |  |
| Water column position | 3 | Demersal or benthic | Benthopelagic | Pelagic |
| Preferred habitat | 3 | Rocky habitats with gravel and sand | Habitats with soft or muddy bottoms | No fishing habitats |
| Day/night catchability | 2 | Higher catch rate at day | No difference between day and night | Higher catch rate at night |
| Diet | 3 | Feed on demersal or bent. organisms | Feed on benthopelagic organisms | Feed on pelagic organisms |
| Depth range | 1 | Less than 40 m | - | Deeper than 40 m |
| Resilience |  |  |  |  |
| Maturity | 3 | Mature individuals $<50 \%$ |  | Mature individuals $>50 \%$ |
| Maximum size | 3 | Max. size $\geq 50 \mathrm{~cm}$ | $16 \mathrm{~cm}<$ max. size $<50 \mathrm{~cm}$ | Max. size $\leq 16 \mathrm{~cm}$ |
| Removal rate | 3 | Catch $\geq 3500$ inds/comp/yr | $1000<$ catch < 3500 inds/comp/yr | Catch $\leq 1000$ inds/comp/yr |
| Reproductive strategy | 2 | Bear live young or brood young | Guard eggs and/or young | Broadcast spawners |
| Hermaphroditism | 1 | Protandric hermaphrodites | Protogynous hermaphrodites | Dioecious |
| Mortality index | 1 | Mortality index $\geq 3.19$ | $0.96<$ mortality index $<3.19$ | Mortality index $\leq 0.96$ |

of dispersal over long distances are less vulnerable to extinction (Dye et al. 1994; Roberts and Hawkins 1999). Thus, the resilience of R -strategist species is generally higher than that of K-strategist species. (2.5) Hermaphroditism - hermaphroditic species, especially protandric species, may be at great risk of extinction because fisheries select individuals of certain sizes and hermaphroditic fish generally only change sex when they reach a certain size, so the fishing effort is, in effect, directed at only one sex - which can have a negative effect on reproduction success (Dye et al. 1994; Roberts and Hawkins 1999; Hawkins and Roberts 2004). (2.6) Mortality index - this index was proposed by Sparre and Venema (1992) and Stobutzki et al. (2001). This index can be derived from the length-frequency of a species and von Bertalanffy growth parameters. Such parameters are not available for most by-catch species, but the index can be calculated as follows:

$$
\text { Mortality index }(Z):\left(L_{\max }-L_{\text {mean }}\right) /\left(L_{\text {mean }}-L_{\min }\right)
$$

in which $L_{\max }$ is the maximum length recorded in the literature, $L_{\text {mean }}$ is the mean length of total number of individuals caught and $L_{\text {min }}$ is the minimum length of the individuals in the sample. In the present study, the mortality index range was calculated (0.13-0.74) and divided into thirds for the division between ranks (Table 1).

## Analysis of criteria

The overall ranks of susceptibility or resilience were calculated according to the equation below:

$$
S_{i}=\sum_{j=1}^{n} R_{i} / \sum_{j=1}^{n} w_{j}
$$

in which $S_{i}$ is the total susceptibility or resilience rank for species $i, w_{j}$ is the weight for criterion $j ; R_{i}$ is the rank of species $i$ for criterion $j$ and $n$ is the number of criteria for each axis.

## Statistical analysis

Data normality was evaluated using the Kolmogorov-Smirnov test (BioEstat 5.0 software - Instituto de Desenvolvimento

Sustentável Mamirauá - Amazonas). The parametric $Z$-test (BioEstat 5.0 software) was used to determine the probability of a captured individual being smaller than size at first maturity and the probability of a captured individual having bred at least once. Correspondence analysis (Multivariate Statistical Package MVSP 3.1 software - Kovach Computing Services - Anglesey, wates) was used to determine and describe the correspondence between species and criteria on the same graph. This multivariate analysis was used only for criteria related to resilience because values regarding susceptibility did not vary among species. Since the variance of the reproductive strategy criterion was equal to zero, this criterion was not applied in the present analysis.

## Results

Among the fish caught, 19 were recorded as by-catch species and belonged to 14 genera and 10 families (Table 2). Of these, $100 \%$ were from reef environments and are used in the aquarium trade and only one species (Equetus lanceolatus) was not authorised for export. In total, 430 individuals were sampled: 147 Holacanthus ciliaris, 46 Holacanthus tricolor, 200 Pomacanthus paru and 37 Chaetodon striatus. Length-frequency distribution by species (Fig. 2) revealed a broad length range among the individuals sampled.

All susceptibility criteria are species-specific and the four species evaluated in the sustainability analysis obtained the same value (1) for this criterion. Rank resilience ranged from 1.92 to $2.54 ; H$. tricolor and $P$. paru obtained the smallest and the largest values respectively (Table 3). Based on these results, it can be affirmed that $H$. tricolor has the least catch sustainability, followed by H. ciliaris and C. striatus. P. paru is the most capable of recovering from a population decline.

Mean and smallest lengths for H. tricolor and C. striatus individuals were under size-at-first-maturity. There was a $71 \%$ probability of $H$. tricolor individuals and a $92 \%$ probability of C. striatus being caught at sizes smaller than first maturity. Contrarily, the probability of captured individuals being larger than maturity size was $76 \%$ for H. ciliaris and $70 \%$ for P. paru. H. ciliaris had the highest mortality index $(Z=3.19)$ and P. paru had the lowest $(Z=0.96)$ (Table 4).

Table 2. Species registered as by-catch, with the respective common names

| Family | Species | Common name |
| :--- | :--- | :--- |
| Sygnathidae | Hippocampus reidi Ginsburg, 1933 | Longsnout seahorse |
| Synodontidae | Synodus foetens (Linnaeus, 1766) | Inshore lizardfish |
| Aulostomidae | Aulostomus maculatus Valenciennes, 1841 | Trumpetfish |
| Sciaenidae | Equetus lanceolatus (Linnaeus, 1758) | Jack-knife fish |
| Sciaenidae | Pareques acuminatus (Bloch \& Schneider, 1801) | Highhat |
| Chaetodontidae | Chaetodon ocellatus Bloch, 1787 | Spotfin butterflyfish |
| Chaetodontidae | Chaetodon striatus Linnaeus, 1758 | Banded butterflyfish |
| Pomacanthidae | Holacanthus ciliaris (Linnaeus, 1758) | Queen angelfish |
| Pomacanthidae | Holacanthus tricolor (Bloch, 1795) | Rock beauty |
| Pomacanthidae | Pomacanthus arcuatus (Linnaeus, 1758) | Gray angelfish |
| Pomacanthidae | Pomacanthus paru (Bloch, 1787) | French angelfish |
| Labridae | Bodianus rufus (Linnaeus, 1758) | Spanish hogfish |
| Labridae | Bodianus pulchellus (Poey, 1860) | Spotfin hogfish |
| Labridae | Halichoeres dimidiatus (Agassiz, 1831) | Brazilian yellowcheek wrasse |
| Labridae | Halichoeres brasiliensis (Bloch, 1791) | Brazilian wrasse |
| Monacanthidae | Cantherhines macrocerus (Hollard, 1855) | Whitespotted filefish |
| Monacanthidae | Stephanolepis hispidus (Linnaeus, 1766) | Planehead filefish |
| Ostracidae | Lactophrys trigonus (Linnaeus, 1758) | Buffalo trunkfish |
| Tetraodontidae | Canthigaster figueiredoi Moura \& Castro, 2002 | Southern Atlantic sharpnose-puffer |

The correspondence analysis for resilience revealed that H. tricolor and C. striatus are linked to the removal index. H. ciliaris and P. paru are associated through maturity criteria. C. striatus and $P$. paru are grouped with maximum size and mortality index criteria respectively. Negative relationships were determined for: $H$. ciliaris and the removal rate and mortality index; H. tricolor and C. striatus with maturity criteria; and P. paru with maximum size. The percentage of the cumulative variation for the two axes was $99.53 \%$ (Fig. 3).

## Discussion

The present study demonstrates that the trap fishery is not selective. The catching of ornamental fish occurs frequently and likely causes considerable impact. Ornamental species are already considered seriously endangered owing to fishery efforts (Cheung et al. 2007). Individuals caught are not landed and are usually returned to the sea (many still alive, according to the fishermen). Despite this, the survival of these individuals is doubtful, as the traps are hauled quickly to surface and problems related to decompression have often been reported (Burns and Restrepo 2002).

The method applied in the present study was developed with the purpose of classifying ornamental fish species according to possible risk of extinction owing to being captured as by-catch. This analysis is influenced by the length range and proportion of young and immature individuals sampled because criteria that are directly related to specimen size are employed, such as length at first maturity and mortality index. Different mesh sizes are used in this fishery, which may have contributed to the broad length range among the individuals sampled. Owing to the small sample size for $H$. tricolor and C. striatus, the length range of the specimens caught may not be representative. Thus, for these species, the analysis must be considered only for demonstration (exploratory) purposes, even though there was a trend towards normality in the length distribution data. The present study is the
first to test a method with such goals directed at trap fisheries and using criteria based on life history.

Specific biological information is optimised when well defined criteria are applied, including characteristics that affect species sensitivity or risk of extinction (Dye et al. 1994; Roberts and Hawkins 1999; Stobutzki et al. 2001). Stobutzki et al. (2001) applied the value 1 in the matrix when there was no specific information for certain criteria. In the present study, all biological information was species-specific. Although the analysis presented is subjective, this may be the only one available to evaluate and monitor multi-specific fisheries (Dulvy et al. 2003), especially newly developed fisheries.

## Susceptibility to capture by traps

Species caught by a given equipment share similar characteristics, such as habitat, diet and period of activity. Thus, reef fish are considered highly susceptible to trap fisheries. Species of Pomacanthidae are widely distributed in depths ranging from 1 to 100 m (Allen 1998; Michael 2004; Froese and Pauly 2007), whereas species of Chaetodontidae occur between 3 and 55 m (Robins and Ray 1986; Allen 1998; Froese and Pauly 2007). The former feed on sponges, zoanthids, tunicates, hydroids, bryozoans and algae (Randall 1967; Allen 1998; Michael 2004). Chaetodontids eat worms, coral polyps and mollusc eggs (Allen 1998). The diet and period of activity of these fish favour their capture because they only feed once during the day (Starck and Davis 1966) and the organisms they eat are sessile, which are generally encrusted on reefs. Dependence on a particularly susceptible habitat (e.g. coral reefs), either alone or combined with overfishing, leads to considerable captures of bycatch species and makes these species all the more vulnerable (Reynolds and Jennings 2000).

## Resilience

Species with late sexual maturity are highly vulnerable to the risk of extinction and consequently have a poor recovery capability


Fig. 2. Length distributions for the four analysed species.
(Dye et al. 1994; Roberts and Hawkins 1999; Sadovy 2005) The correspondence analysis reveals the clustering of H. ciliaris and $P$. paru with the maturity criterion owing to the fact that more than a half of the sampled individuals had bred at least once. The opposite was found for H. tricolor and C. striatus, for which, respectively, $70 \%$ and $92 \%$ of individuals sampled were immature. Myers and Worm (2005) stated that the risk of extinction is very high if recruits are being captured and low when fish are caught after first sexual maturity. Thus, the maturity criterion
had a positive influence on the classification of H. ciliaris and P. paru in relation to resilience.

Large body size is often correlated with other vulnerability factors, such as late maturity, and substantially increases the possibility of being caught in traps (Reynolds and Jennings 2000 Reynolds et al. 2002; Cheung et al. 2007). Body size is a useful measure in evaluating species resilience owing to its relationship with the intrinsic rate of increase of a population. Thus, it can be applied to populations and species for which minimal biological data are available (Denney et al. 2002). In the Pomacanthidae, the genera Holacanthus and Pomacanthus are the longest (Bellwood et al. 2004). Among the analysed fish, P. paru was the second largest, but exhibited the greatest resilience. This can be explained by the fact that most individuals caught were fit for reproduction and the species had the lowest mortality rate.

The demand for marine ornamental fish increased in the 1980s and 1990s (Chan and Sadovy 1998). Concerns have been raised regarding its negative effect on reef fish and coral habitats because nearly all ornamental marine fish are taken from the wild (Andrews 1990; Wood 2001a). The potential for overexploitation from the aquarium trade is high owing to the high selectivity of this activity and the large number of fish collected (Wood 2001a). It is estimated that most commercialised ornamental fish are juveniles and less than 10 cm in standard length (Chan and Sadovy 1998). Species of Pomacanthidae and Chaetodontidae are often the most important families for export in terms of number and value (Wood 2001a). In the Brazilian aquarium trade, these two families are among the most representative in species richness (Gasparini et al. 2005). In the state of Ceará (one of the main centres of the Brazilian ornamental fish trade), H. ciliaris, P. paru, Hippocampus erectus, Pomacanthus arcuatus and Holacanthus tricolor made up $50 \%$ of the total trade between 1995 and 2000 (Monteiro Neto et al. 2003) Among the species evaluated, $H$. ciliaris is the most harvested by the Brazilian aquarium trade (IBAMA - Federal Act 56/04). The correspondence analysis corroborates this statement, revealing a negative relationship between $H$. ciliaris and removal rate.

Regarding reproductive strategy, all species evaluated are broadcast spawners (Thresher 1980, 1984). Therefore, they are less vulnerable to extinction owing to their widespread distribution and the high recolonisation potential of depleted populations (Malakoff 1997; McKinney 1997). However, larval behaviour spawning events and local oceanography processes can influence larval dispersal by increasing local retention (Cowen et al. 2006; Rocha et al. 2007). Hawkins et al. (2000) stated that, despite reef fish being broadcast spawners, their geographic distribution is small: $24 \%$ are restricted to less than $800000 \mathrm{~km}^{2}$ and $9 \%$ are restricted to less than $50000 \mathrm{~km}^{2}$. Based on these statements, it is possible to infer that being a broadcast spawner does not ensure low vulnerability to extinction.

Hermaphroditic species are likely to be very sensitive to overfishing because individuals need to attain a certain length for the sex change to occur (Francis 1992). If fishing affects the growth of the fish such that sexual inversion does not occur, this could result in a non-reproductive population and even cause the species to disappear in intensely exploited areas (Hawkins and Roberts 2004). Among the species analysed in the present study, those from the Holacanthus genus are protogynous hermaphrodites (Thresher 1980, 1984; Moyer et al. 1983;

Table 3. The ranking of the species on the criteria on the resilience axis

| Species/weight | Resilience |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 3 Maturity | $3$ <br> Maximum size | $3$ <br> Removal rate | $2$ <br> Reproductive strategy | 1 Hermaphroditism | Mortality index | Rank |
| Holacanthus ciliaris | 3 | 2 | 1 | 3 | 2 | 1 | 2.08 |
| Holacanthus tricolor | 1 | 2 | 2 | 3 | 2 | 2 | 1.92 |
| Pomacanthus paru | 3 | 2 | 2 | 3 | 3 | 3 | 2.54 |
| Chaetodon striatus | 1 | 3 | 3 | 3 | 3 | 2 | 2.46 |

Table 4. The length at first capture, length at maturity, probability that individuals caught are below the length at maturity, probability of breeding, mean and maximum length (max. length) of the species and the mortality index ( $Z$ ) of four species of fish

| Species | $n$ | $\mathrm{L}^{\prime}$ <br> $(\mathrm{cm})$ | Lm <br> $(\mathrm{cm})$ | Prob. $\mathrm{L}^{\prime}<\mathrm{Lm}$ <br> $(\mathrm{cm})$ | Prob. of breeding | $\mathrm{L}_{\text {mean }} \pm$ s.e. <br> $(\mathrm{cm})$ | Max. length <br> $(\mathrm{cm})$ |  |
| :--- | ---: | ---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Holacanthus ciliaris | 147 | 20.88 | 24.3 | $P=0.24$ | $P=0.76$ | $26.58 \pm 0.2672$ | 45 (Allen 1998) |  |
| Holacanthus tricolor | 46 | 11.32 | 19 | $P=0.71$ | $P=0.29$ | $17.61 \pm 0.3646$ | 35 (Allen 1998) |  |
| Pomacanthus paru | 200 | 13.44 | 25 | $P=0.30$ | $P=0.70$ | $28.30 \pm 0.4510$ | 41 (Cervigón 1993) |  |
| Chaetodon striatus | 37 | 9.09 | 13.2 | $P=0.92$ | $P=0.07$ | $11.26 \pm 0.2257$ | 16 (Lieske and Myers 1994) | 2.19 |

$n=$ number of individuals, $\mathrm{L}^{\prime}=$ length at first capture, $\mathrm{Lm}=$ length at maturity, Prob.$=$ probability.


Fig. 3. Correspondence analysis showing the relationship between species and criteria used to evaluate the recovery capacity. Hol. cil. = Holacanthus ciliaris, Hol. tri. = Holacanthus tricolor, Cha. str. = Chaetodon striatus, Pom. par. = Pomacanthus paru, Max. size = maximum size.

Allen 1998). These species are heavily exploited by the aquarium trade, in which most individuals collected are small in size (Chan and Sadovy 1998) and probably belong to the same sex (i.e. female). H. tricolor and H. ciliaris revealed the lowest recovery capacity. However, according to the correspondence
analysis, the hermaphroditism criterion had no influence over their classification regarding resilience. This may be explained by the absence of protandric species in the analysis because such species are more sensitive than protogynous species (Sadovy and Shapiro1987; Hawkins and Roberts 2004).

Throughout the life cycle, individuals are exposed to different types of environmental pressure. The natural mortality rate decreases as the fish grows and becomes less vulnerable to predators. The mortality coefficient used in the present study considered data on maximum and mean catch length (Beverton and Holt 1956). H. ciliaris had the highest mortality index among the species analysed owing to the mean catch size, which was below that found in the literature (Allen 1998). This coefficient along with the criterion related to the removal rate - had a negative influence on the resilience of this species.

Resilience ranks were different for the four species analysed, even for those belonging to the same family. Stobutzki et al. (2001) stated that the catch of a species is not sustainable if it has both high resilience and susceptibility. The results obtained for C. striatus and P. paru are in agreement with this statement because these species revealed considerable resilience, but were highly susceptible according to the ecological information (such as diet, preferred habitat and depth range).

The method employed in the present study (susceptibility and resilience criteria) is efficient for evaluating the impact of newly formed fisheries with few available data that occur in areas with high species richness (Dulvy et al. 2003, 2004), such as reef environments. However, in order to incorporate the results of this study in fishery management measures, vulnerability analysis (VA) can be utilised as a component of a risk analysis when only qualitative data is available and researchers lack an understanding of cause/effect relationships (Walker et al. 2002; McFadden 2007).

Most fishing equipment is not selective and many fish are caught as by-catch, even when there is only one target species. These species are highly affected by fishery efforts because bycatch will continue to be fished as long as it remains viable to catch the target species. Trap fisheries targeting reef fish have recently developed in Brazil and are on the rise in the north-eastern region. Regulatory agencies often take a long time to react and severe declines in non-target species go unperceived. Thus, little is known regarding the impact of this activity and such lack of information hinders regulatory efforts. The method presented here is an appropriate, practical tool for fishery management and the assessment of catch sustainability in multi-species fisheries on which there is limited available data. It can also be employed to determine which species are at a possible risk of extinction owing to being by-catch. Furthermore, it is important to consider that to reduce the extinction threat posed on those species, a socioeconomic VA is required in order to develop the appropriate institutional framework/outreach program to the fishers necessary to address this ecological challenge.

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## References

Allen, G. R. (1998). Introducing angelfish. In 'A Guide to Angelfish and Butterflyfish'. pp. 8-12. (Mergus Publishers: Melle.)

Andrews, C. (1990). The ornamental fish trade and conservation. Journal of Fish Biology 37, 53-59. doi:10.1111/J.1095-8649.1990.TB05020.X
Araújo, M. E., and Albuquerque Filho, A. C. (2005). Biologia das principais espécies de peixes ornamentais marinhos do Brasil: uma revisão bibliográfica e documental. Boletim Técnico Científico do CEPENE 13, 109-154
Bellwood, D. R., van Herwerden, L., and Konow, N. (2004). Evolution and biogeography of marine angelfish (Pisces: Pomacanthidae) Molecular Phylogenetics and Evolution 33, 140-155. doi:10.1016/ J.YMPEV.2004.04.015

Beverton, R. J. H., and Holt, S. J. (1956). A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapports et procés-verbaux des Reunions Conseil permanent International pour l'Exploration de la mer 140, 67-83.
Burns, K. M., and Restrepo, V. (2002). Survival of reef fish after rapid depressurization: field and laboratory studies. American Fisheries Society Symposium 30, 148-151.
Carvalho-Filho, A. (1999). As espécies e suas famílias. In 'Peixes: Costa Brasileira'. pp. 40-283. (Editora Melro: São Paulo.)
Casey, J. M., and Myers, R. A. (1998). Near extinction of a large, widely distributed fish. Science 281, 690-691. doi:10.1126/SCIENCE. 281 5377.690

Cervigón, F. (1993). Pomacanthidae. In 'Los Peces Marinos de Venezuela' pp. 339-346. (Fundación Científica Los Roques: Caracas.)
Chan, T. T. C., and Sadovy, Y. (1998). Profile of the marine aquarium fish trade in Hong Kong. Aquarium Sciences and Conservation 2, 197-213 doi:10.1023/A:1009644730784
Cheung, W. W. L., Watson, R., Morato, T., Pitcher, T. J., and Pauly, D. (2007) Intrinsic vulnerability in the global fish catch. Marine Ecology Progres Series 333, 1-12. doi:10.3354/MEPS333001
Cowen, R. K., Paris, C. B., and Srinivasan, A. (2006). Scaling of connectivity in marine populations. Science 311, 522-527. doi:10.1126 SCIENCE. 1122039
Dalzell, P., Adams, T. J. H., and Polunin, N. V. C. (1996). Coastal fisheries in the Pacific Islands. Oceanography and Marine Biology: An Annual Review 34, 395-531
Denney, N. H., Jennings, S., and Reynolds, J. D. (2002). Life-history correlates of maximum population growth rates in marine fish. Proceedings of the Royal Society of London 269, 2229-2237. doi:10.1098 RSPB.2002.2138
Dulvy, N. K., Sadovy, Y., and Reynolds, J. D. (2003). Extinction vulnerability in marine populations. Fish and Fisheries 4, 25-64. doi:10.1046/J.1467 2979.2003.00105.X

Dulvy, N. K., Ellis, J. R., Goodwin, N. B., Grant, A., Reynolds, J. D., and Jennings, S. (2004). Methods of assessing extinction risk in marine fish. Fish and Fisheries 5, 255-276. doi:10.1111/J.1467-2679.2004 00158.X

Dye, A. H., Schleyer, M. H., Lambert, G., and Lasiak, T. A. (1994). Biological options for the management of the exploitation of intertidal and subtidal resources. In 'Rocky Shores: Exploitation in Chile and South Africa' (Ed. W. R. Siegfried.) pp. 131-154. (Springer-Verlag: New york)
Eayrs, S. (2007). Guía para Reducir la Captura de Fauna Incidental (Bycatch) en las Pesquerías por Arrastre de Camarón Tropical. FAO, Rome. Available at ftp://ftp.fao.org/FI/DOCUMENT/rebyc/a1008s.pdf [Accessed 9 December 2008].
Francis, R. C. (1992). Sexual lability in teleosts: developmental factors. The Quarterly Review of Biology 67, 1-18. doi:10.1086/417445
Froese, R., and Pauly, D. (2007). FishBase. Available at http:// www.fishbase.org [Accessed 29 October 2007].
Garrison, V. H., Rogers, C. S., and Beets, J. (1998). Of reef fish, overfishing and in situ observations of fish traps in St. John, U. S. Virgin Islands Revista de Biologia Tropical 46, 41-59
Garrison, V. H., Rogers, C. S., Beets, J., and Friedlander, A. M (2004). The habitats exploited and the species trapped in a Caribbean
island trap fishery. Environmental Biology of Fishes 71, 247-260. doi:10.1007/S10641-004-0301-X
Gasparini, J. L., Floeter, S. R., Ferreira, C. E. L., and Sazima, I. (2005). Marine ornamental trade in Brazil. Biodiversity and Conservation 14, 2883-2899. doi:10.1007/S10531-004-0222-1
Hawkins, J. P., and Roberts, C. M. (2004). Effects of fishing on sexchanging Caribbean parrotfish. Biological Conservation 115, 213-226. doi:10.1016/S0006-3207(03)00119-8
Hawkins, J. P., Roberts, C. M., and Clark, V. (2000). The threatened status of restricted-range coral reef fish species. Animal Conservation 3, 81-88. doi:10.1111/J.1469-1795.2000.TB00089.X
Hourigan, T. F., Stanton, F. G., Motta, P. J., Kelley, C. D., and Carlson, B. (1989). The feeding ecology of three species of Caribbean angelfish (family Pomacanthidae). Environmental Biology of Fishes 24, 105-116. doi:10.1007/BF00001281
Hutchings, J. A. (2001). Conservation biology of marine fish: perceptions and caveats regarding assignment of extinction risk. Canadian Journal of Aquatic Sciences 58, 108-121. doi:10.1139/CJFAS-58-1-108
Kelleher, K. (2005). Discards in the world's marine fisheries. An update. FAO Fisheries Technical Paper No 470. FAO, Rome. Available at http://www.fao.org/docrep/008/y5936e/y5936e00.htm [Accessed 9 December 2008].
Lieske, E., and Myers, R. (1994). Spadefish and butterflyfish. In 'Collins Pocket Guide. Coral Reef Fish. Indo-Pacific and Caribbean Including the Red Sea'. pp. 161-162. (Princeton University Press: Princeton, NJ.)
Mahon, R., and Hunte, W. (2001). Trap mesh selectivity and the management of reef fish. Fish and Fisheries 2, 356-375. doi:10.1046/J.14672960.2001.00054.X

Malakoff, D. (1997). Extinction on the high seas. Science 277, 486-488. doi:10.1126/SCIENCE.277.5325.486
McFadden, L. (2007). Vulnerability analysis in environmental management: widening and deepening its approach. Environmental Conservation 34, 195-204. doi:10.1017/S0376892907004195
McKinney, M. L. (1997). Extinction vulnerability and selectivity: combining ecological and paleontological views. Annual Review of Ecology and Systematics 28, 495-516. doi:10.1146/ANNUREV.ECOLSYS. 28.1.495

Michael, S. W. (2004). Family Pomacanthidae/angelfish. In ‘Angelfish and Butterflyfish'. pp. 210-321. (T. F. H. Publications: Neptune City, NJ.)
Milton, D. A. (2001). Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's Northern Prawn Fishery. Biological Conservation 101, 281-290. doi:10.1016/S0006-3207(00)00232-9
Monteiro Neto, C., Cunha, F. E. A., Nottingham, M. C., Araújo, M. E., Rosa, I. L., and Barros, G. M. L. (2003). Analysis of the marine ornamental fish trade at Ceará State, northeast Brazil. Biodiversity and Conservation 12, 1287-1295. doi:10.1023/A:1023096023733
Moyer, J. T., Thresher, R. E., and Colin, P. L. (1983). Courtship, spawning and inferred social organization of American angelfish (genera Pomacanthus, Holacanthus and Centropyge: Pomacanthidae). Environmental Biology of Fishes 9, 25-39. doi:10.1007/BF00001056
Myers, R. A., and Worm, B. (2005). Extinction, survival or recovery of large predatory fish. Philosophical Transactions of the Royal Society 360, 13-20. doi:10.1098/RSTB.2004.1573
Nottingham, M. C., Cunha, F. E., and Monteiro Neto, C. (2000). Captura de peixes ornamentais marinhos no Ceará. Arquivos Ciências do Mar 33, 113-118.
Pope, J. G., MacDonald, D. S., Dann, N., Reynolds, J. D., and Jennings, S. (2000). Gauging the impact of fishing mortality on nontarget species. ICES Journal of Marine Science 57, 689-696. doi:10.1006/ JMSC. 2000.0729
Randall, J. E. (1967). Food habits of reef fishes of the West Indies. Studies on Tropical oceanography 5, 665-847.
Reynolds, J. D., and Jennings, S. (2000). The role of animal behavior in marine conservation. In 'Behavior and Conservation'. (Eds
L. M. Gosling and W. J. Shuterland.) pp. 147-168. (Cambridge University Press: Cambridge, UK.)
Reynolds, J. D., Jennings, S., and Dulvy, N. K. (2001). Life histories of fish and population responses to exploitation exploitation. In 'Conservation of Exploited Species'. (Eds J. D. Reynolds, G. M. Mace, K. H. Redford and J. G. Robinson.) pp. 147-168. (Cambridge University Press: Cambridge, UK.)
Reynolds, J. D., Dulvy, N. K., and Roberts, C. M. (2002). Exploitation and other threats to fish conservation. In 'Fish and Fisheries Handbook'. (Eds P. J. B. Hart and J. D Reynolds.) pp. 319-341. (Blackwell Science: Oxford.)
Ribeiro, F. P. (2004). Composição da biocenose e abundância relativa de peixes capturados com covos nos Estados do Rio Grande do Norte e Pernambuco. Boletim Técnico Científico do CEPENE 12, 113-128.
Roberts, C. M., and Hawkins, J. P. (1999). Extinction risk in the sea. Trends in Ecology \& Evolution 14, 241-246. doi:10.1016/S0169-5347(98) 01584-5
Robins, C. R., and Ray, C. G. (1986). Butterflyfish: family Chaetodonidae. In 'A Field Guide to Atlantic Coast Fish of North America'. pp. 192-194. (Houghton Mifflin Company: New York.)
Rocha, L. A., Craig, M. T., and Bowen, B. W. (2007). Phylogeography and the conservation of coral reef fish. Coral Reefs 26, 501-512.
Sadovy, Y. (2005). Trouble on the reef: the imperative for managing vulnerable and valuable fisheries. Fish and Fisheries 6, 167-185. doi:10.1111/ J.1467-2979.2005.00186.X

Sadovy, Y., and Shapiro, D. Y. (1987). Criteria for the diagnosis of hermaphroditism in fishes. Copeia 1987, 136-156. doi:10.2307/1446046
Sparre, P., and Venema, S. C. (1992). Introduction to tropical fish stock assessment, part 1. FAO Fisheries Technical Paper No 306. FAO: Rome. Available at ftp://ftp.fao.org/docrep/fao/w5449e/w5449e00.pdf [Accessed 9 December 2008].
Starck, W. A. I., and Davis, W. P. (1966). Night habits of fish of Alligator Reef, Florida. Ichthyologica 38, 313-356.
Stobutzki, I., Blaber, S., Brewer, D., Fry, G., Heales, D., et al. (2000). Ecological sustainability of bycatch and biodiversity in prawn trawl fisheries. Final Report Project 96/257. Fisheries Research and Development Corporation, Canberra.
Stobutzki, I., Miller, M., and Brewer, D. (2001). Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch. Environmental Conservation 28, 167-181. doi:10.1017/ S0376892901000170
Swingle, W. E., Dammann, A. E., and Yntema, A. N. (1970). Survey of the commercial fishery of the Virgin Islands of the United States. Proceedings of the Gulf and Caribbean Fisheries Institute 20, 110-121.
Thresher, R. E. (1980). Angelfish. In 'Reef fish: Behavior and Ecology on the Reef and in the Aquarium'. pp. 37-46. (The Palmetto Publishing Company: St Petersburg, FL.)
Thresher, R. E. (1984). Angelfish (Pomacanthidae). In 'Reproduction in Reef Fish'. pp. 244-261. (T. F. H. Publications: Neptune City, NJ.)
Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., Peterson, G. D., and Pritchard, R. (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. Conservation Ecology 6, 14.
Wolff, N., Grober-Dunsmore, R., Rogers, C. S., and Beets, J. (1999). Management implications of fish trap effectiveness in adjacent coral reef and gorgonian habitats. Environmental Biology of Fishes 55, 81-90. doi:10.1023/A:1007430407540
Wood, E. M. (2001a). 'Collection of Coral Reef Fish for Aquaria: Global Trade, Conservation Issues and Management Strategies.' (Marine Conservation Society: Ross-on-Wye, UK.)
Wood, E. M. (2001b). Global advances in conservation and management of marine ornamental resources. Aquarium Science and Conservation 3, 65-77. doi:10.1023/A:1011391700880

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