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UNIVERSIDADE ESTADUAL PAULISTA – UNESP
CENTRO DE AQUICULTURA DA UNESP

Síntese emergética na aquicultura: estratégias para promover a sustentabilidade da tilapicultura em tanque-rede.

Luiz Henrique Castro David

Jaboticabal, São Paulo
2018

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Orientadora: Dra. Fabiana Garcia Scaloppi

Dissertação apresentada ao Programa de Pós-graduação em Aquicultura do Centro de Aquicultura da UNESP - CAUNESP, como parte dos requisitos para obtenção do título de Mestre.

Jaboticabal, São Paulo
2018

David, Luiz Henrique Castro
D249s Síntese emergética na aquicultura: estratégias para promover a sustentabilidade da tilapicultura em tanque-rede / Luiz Henrique Castro David. – – Jaboticabal, 2018
66 p. : il. ; 29 cm

Dissertação (mestrado) - Universidade Estadual Paulista, Centro de Aquicultura, 2018
Orientadora: Fabiana Garcia Scaloppi
Banca examinadora: Feni Dalano Roosevelt Agostinho, Luís Alberto Ambrósio
Bibliografia

1. Emergia. 2. Perifíton. 3. Sustentabilidade. I. Título. II. Jaboticabal-Centro de Aquicultura.

CDU 639.3.043

Ficha catalográfica elaborada pela Seção Técnica de Aquisição e Tratamento da Informação – Diretoria Técnica de Biblioteca e Documentação - UNESP, Câmpus de Jaboticabal.

unesp UNIVERSIDADE ESTADUAL PAULISTA

Unidade Complementar - Jaboticabal

CERTIFICADO DE APROVAÇÃO

TÍTULO: SÍNTESE EMERGÉTICA NA AQUICULTURA: ESTRATÉGIAS PARA PROMOVER A SUSTENTABILIDADE DA TILAPICULTURA EM TANQUE-REDE.

AUTOR: LUIZ HENRIQUE CASTRO DAVID
ORIENTADORA: FABIANA GARCIA

Aprovado como parte das exigências para obtenção do Título de Mestre em AQUICULTURA, pela Comissão Examinadora:

Fabiana Garcia

Profa. Dra. FABIANA GARCIA SCALOPPI
Departamento de Descentralização do Desenvolvimento / APTA / Votuporanga-SP

Prof. Dr. FENI DALANO ROOSEVELT AGOSTINHO
Laboratório de Produção e Meio Ambiente / Universidade Paulista, UNIP, São Paulo-SP

Prof. Dr. LUÍS ALBERTO AMBRÓSIO
. / Instituto de Zootecnia, Nova Odessa-SP

Jaboticabal, 23 de fevereiro de 2018.

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AGRADECIMENTOS

Agradeço a todos que de alguma forma contribuíram com o planejamento, execução e finalização do presente trabalho.

Agradeço, em especial:

A minha família pelo apoio, confiança, incentivo, carinho e por sempre se mostrarem dispostos a me auxiliar em todas as minhas iniciativas e decisões.

A Fabiana Garcia pela oportunidade, amizade, confiança e acolhida. Além da competência e comprometimento como profissional e orientadora.

A Sara Pinho pela cumplicidade, por querer e ter participado de todas as etapas do estudo. Além do apoio e incentivo em todos os momentos da minha vida, bons ou ruins.

A Daiane Romera pela amizade, confiança e por sempre estar disposta a ajudar no que for necessário.

A todos os funcionários e amigos do IAC – Votuporanga e Instituto de Pesca – SJ do Rio Preto por todo suporte e atenção.

Aos colegas e amigos que Jaboticabal e o CAUNESP me proporcionaram nesse período.

A todos vocês, MUITO OBRIGADO.

APOIO FINANCEIRO

À CAPES, pela concessão da bolsa de mestrado.

À FAPESP, Processo nº 2014/08479-6 e Processo nº 2016/07696-9.

RESUMO

O rápido crescimento da aquicultura pode acompanhar muitos problemas econômicos, sociais e ambientais. Nesse sentido, muitos sistemas, modelos e técnicas de produção têm sido criados e utilizados para gerenciar o uso dos recursos, diminuir os impactos negativos e tornar a aquicultura uma atividade mais sustentável. No entanto, não se sabe quais desses métodos é realmente sustentável. Sendo assim, o objetivo desse trabalho foi fazer uma revisão sobre o uso da síntese emergética para mensurar a sustentabilidade na produção aquícola. Além de aplicar este método para identificar as contribuições advindas da natureza e da economia no sistema de produção de tilápias em tanques-rede; e avaliar se o uso do perifíton como alimento complementar e a redução da densidade de estocagem melhoram os indicadores de sustentabilidade deste sistema. Para isso, foram avaliados e comparados um sistema com densidade de estocagem de 80 kg.m^{-3}, 100% de alimentação, sem substrato e sem perifíton; um segundo sistema que utilizou a mesma densidade de estocagem de 80kg.m^{-3}, 50% de alimentação, com substrato e perifíton; e um terceiro com menor densidade de estocagem (40 kg.m^{-3}), 50% de alimentação, com substrato e perifíton. Para avaliação emergética foram calculados a renovabilidade, transformidade, razão de rendimento emergético, razão de investimento emergético, razão de carga ambiental, razão de troca emergética e índice de sustentabilidade emergética. A diminuição da densidade de estocagem de peixes e da quantidade de ração, aliadas ao uso de perifíton, melhoraram todos os indicadores de sustentabilidade avaliados. Apesar dessa melhora, a redução na densidade demonstrou baixa produtividade. O estudo mostra que técnicas que visem aumentar o uso de recursos renováveis e diminuir os da economia devem ser incentivadas na produção de tilápias em tanque-rede, tornando evidente a necessidade de políticas públicas que incentivem o uso de sistemas sustentáveis.

PALAVRAS-CHAVE: emergia, perifíton, densidade, ração, sustentabilidade.

ABSTRACT

The rapid growth of aquaculture may be accompanied by several economic, social and environmental problems. In this sense, many production systems, models and techniques have been created and used to manage the use of resources, reduce negative environmental impacts, thus making aquaculture a more sustainable activity. However, it is not known which production systems and management practices are truly sustainable, even though the development and application of these technologies are fundamental for the sustainability of the activity. Therefore, the objective of this study was to review the emergy synthesis to measure sustainability in aquaculture production. Despite applying the emergy analysis to identify the contributions of nature and economy in a tilapia cage farming and evaluating if the periphyton exploitation as a complementary food source and a way of reducing stocking densities improves the sustainability indicators of this system. For this purpose, a system with a 80 kg m^{-3}, 100% of feed, without substrate and without periphyton was compared with two other systems: one with the same stocking density of 80 kg m^{-3} and 50% of feed with substrate and periphyton and a second one with a lower stocking density (40 kg m^{-3}) and 50% of feed, substrate and periphyton. For the emergy synthesis, the following variables were calculated: renewability, transformity, emergy yield ratio, emergy investment ratio, environmental loading ratio, emergy exchange ratio and emergy sustainability index. Reduced stocking densities and feed supply, together with the use of periphyton, improved all the evaluated sustainability indicators. Despite this improvement, reduced densities did not demonstrate ecosystem efficiency, due to low productivity rates. This study showed that techniques that aim to increase the use of renewable resources and reduce economy ones, must be encouraged in tilapia productions in cages, making the need of public policies evident, which motivate producers that adopt more sustainable production systems.

KEYWORDS: emergy, periphyton, density, feed, sustainability.

CAPÍTULO 1

INTRODUÇÃO GERAL - ARTIGO DE REVISÃO

Manuscrito formatado nas normas da revista *Aquaculture*

1. Introduction

Consumption of aquatic food has increased in recent years, driven by population growth and increased preference for healthy animal protein sources (Moura et al., 2016). However, fisheries continue providing constant amount of fish and have failed in supply the growing human demand. This scenario has resulted in a rapid growth of aquaculture, making this activity the fastest growing agricultural practice in the last decades (FAO, 2016). In addition to this increase, there are many concerns about the future of aquaculture production, especially in regarding to the negative environmental impacts that this activity may cause (Henriksson et al., 2017; Nhu et al., 2016). Depending on the aquaculture system adopted, the cultivation of aquatic organisms can use natural resources irresponsibly and interfere in the maintenance of biodiversity, through eutrophication of water bodies, pollution by drug residues and dissemination of diseases in the natural environment (Asche et al., 2009; Ottinger et al., 2016; Fry et al., 2016). On the other hand, aquaculture can also generate impacts that can positively affect the environment, e.g. ecosystem services promoted by aquaculture (Aubin et al., 2014). Ecosystem services are made available when the productive process is used to improve the ecosystem, for example, the bivalve farming that improve water quality or the application of wetlands for effluent treatment (Travaini-Lima and Sipaúba-Tavares, 2012; McDonough et al., 2014; Lemasson et al., 2017; Han et al., 2017).

The monetary valuation of the impacts generated by aquaculture is included in the concept of externalities (Aubin et al., 2014). Externalities can be defined as the positive or negative effects of a decision on those who have not taken part of the decision. In aquaculture, positive externalities can be considered when people involuntarily benefit of the activity, such by jobs generation and financial market movement (Aubin et al., 2014). Negative externalities include water pollution and loss of biodiversity, for example (Aubin et al., 2014; Walton et al., 2015; Villasante et al., 2015). In this sense, public and private institutions are trying to promote and develop sustainability of aquaculture, ensuring the maximization of positive externalities (Alexander et al., 2016) and reducing the negative impacts of the activity.

Many definitions for sustainability are found in the literature (Glavic and Lukman, 2007; Ahi and Searcy, 2013). For Johnston et al. (2007) and Valenti et al. (2011), the sustainability can be defined as the management of natural, financial, technological and institutional resources, in order to ensure the welfare and supply the needs of present and future generations. Some aquaculture systems, models and production techniques have been created and used to manage the use of resources and reduce negative impacts on the environment (Boyd et al., 2007). However, many of these initiatives are not based on the concept of sustainability, but on the adoption of specific actions to improve the efficiency of the systems and legalize the production models, such as Best Management Practices (BMP). The use of these practices leads aquaculture to sustainability, but both should not be confused. Some BMPs, such as the reduction on the need for water or medicines, cannot make the production sustainable, especially if is necessary a higher input of non-renewable resources to achieve these desirable results (Read and Fernandes, 2003; Valenti et al., 2010).

The application of BMPs in production systems is essential to the aquaculture development, however not yet known which of these practices lead the aquaculture to sustainability (Valenti et al., 2011). This is because sustainability theme in aquaculture is recent and there are few research groups dedicated to applying methods of sustainability analysis in their studies (Hau and Bakshi, 2004; Chen et al., 2017), even though assessment methods are essential to indicate actions that will make aquaculture a sustainable activity (Valenti et al., 2011; Kimpara et al., 2012). The low use of these methods and the disorderly growth of the activity generate many incorrect management and inefficient environmental protection laws, which do not contribute to the effective development of aquaculture (Boyd, 2003).

Studies that measure the sustainability of aquaculture production are essential to generate more efficient and ecological systems and consequently new technologies (Valenti et al., 2010; Garcia and Kimpara, 2012). In this sense, there are methods that can be applied to show the strengths and weaknesses of each system, besides indicating strategies of how to improve them (Fezzardi et al., 2013). Among the methods available, the emergy synthesis (Odum, 1996) stands out to be a flexible and scientifically robust method. This method can be applied in aquaculture to provide concrete information for decision-making and guide the activity to sustainability (Garcia et al., 2014). In this sense, it is necessary to know the overview of applicability of emergy synthesis in aquaculture, to direct future studies and propose practical strategies for the sustainable development of aquaculture. Thus, the aim of this review was to characterize the emergy synthesis and to discuss the main applications and potentialities of its use in aquaculture systems.

6. Conclusion

The set of information provided by ES supplies technical-scientific subsidies to ensure the planning and adoption of more sustainable production systems in order to ensure the success of long-term activity. The results of using ES to assess aquaculture sustainability indicate the need to increase the use of renewable resources using natural food and integrated production system. In addition, the results of this method allow discussions about public policies for aquaculture and the valuation of natural resources. These strategies can be part of sustainability guidelines in fish production, because they promote the welfare of the community, the environment and the local economy.

7. References

Agostinho, F., Ambrósio, L.A., Ortega, E., 2010. Assessment of a large watershed in Brazil using Emergy Evaluation and Geographical Information System. Ecol. Modell. 221, 1209–1220. doi:10.1016/j.ecolmodel.2009.12.019

Ahi, P., Searcy, C., 2013. A comparative literature analysis of definitions for green and sustainable supply chain management. J. Clean. Prod. 52, 329–341. doi:10.1016/j.jclepro.2013.02.018

Alexander, K.A., Angel, D., Freeman, S., Israel, D., Johansen, J., Kletou, D., Meland, M., Pecorino, D., Rebours, C., Rousou, M., Shorten, M., Potts, T., 2016. Improving sustainability of aquaculture in Europe: Stakeholder dialogues on Integrated Multi-Trophic Aquaculture (IMTA). Environ. Sci. Policy 55, 96–106. doi:10.1016/j.envsci.2015.09.006

Amaral, L.P., Martins, N., Gouveia, J.B., 2016. A review of emergy theory, its application and latest developments. Renew. Sustain. Energy Rev. 54, 882–888. doi:10.1016/j.rser.2015.10.048

Asche, F., Roll, K.H., Tveteras, R., 2009. Economic inefficiency and environmental impact: An application to aquaculture production. J. Environ. Econ. Manage. 58, 93–105. doi:10.1016/j.jeem.2008.10.003

Aubin, J., Rey-Valette, H., Mathé, S., Wilfart, A., Legendre, M., Slembrouck, J., Chia, E., Masson, G., Callier, M., Blancheton, J. P., Tocqueville, A., Caruso, D., Fontaine, P., 2014. Guide for implementing ecological intensification of aquaculture systems. 131 pp.

Ayroza, L.M. da S., Romagosa, E., Ayroza, D.M.M. de R., Filho, J.D.S., Salles, F.A., 2011. Custos e rentabilidade da produção de juvenis de tilápia-do-nilo em tanques-rede utilizando-se diferentes densidades de estocagem. Rev. Bras. Zootec. 40, 231–239. doi:10.1590/S1516-35982011000200001

Boyd, C.E., 2003. Guidelines for aquaculture effluent management at the farm-level. Aquaculture 226, 101–112. doi:10.1016/S0044-8486(03)00471-X

Boyd, C.E., Tucker, C., McNevin, A., Bostick, K., Clay, J., 2007. Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture, Reviews in Fisheries Science. doi:10.1080/10641260701624177

Brown, M.T., Campbell, D.E., De Vilbiss, C., Ulgiati, S., 2016. The geobiosphere emergy baseline: A synthesis. Ecol. Modell. 339, 92–95. doi:10.1016/j.ecolmodel.2016.03.018

Brown, M.T., Cohen, M.J., Sweeney, S., 2009. Predicting national sustainability: The convergence of energetic, economic and environmental realities. Ecol. Modell. 220, 3424–3438. doi:10.1016/j.ecolmodel.2009.08.023

Brown, M.T., S. Brandt-Williams, D. Tilley, S. Ulgiati. 2000. Emergy Synthesis: An Introduction. Proceedings of the First Biennial Emergy Analysis Research Conference. The center of environmental Policy. Department of Environmental Engineering Ciences, University of Florida, Gainesville, Florida, USA. 1-14

Brown, M.T., Ulgiati, S., 2002. Emergy evaluation and environmental loading of electricity production systems. J. Clean. Prod. 10, 321–334.

Brown, M.T., Ulgiati, S., 2004. Emergy analysis and environmental accounting. Encycl. Energy. doi:10.1016/B0-12-176480-X/00242-4

Brown, M.T., Ulgiati, S., 2016. Emergy assessment of global renewable sources. Ecol. Modell. 339, 148–156. doi:10.1016/j.ecolmodel.2016.03.010

Campbell, D.E., 2016. Emergy baseline for the Earth: A historical review of the science and a new calculation. Ecol. Modell. 339, 96–125. doi:10.1016/j.ecolmodel.2015.12.010

Campbell, D.E., Brandt-Williams, S.L., Cai, T., 2005. Current Technical Problems in Emergy Analysis. Proc. from Third Bienn. Emergy Conf.

Cavalett, O., Queiroz, J.F. De, Ortega, E., 2006. Emergy assessment of integrated production systems of grains, pig and fish in small farms in the South Brazil. Ecol. Modell. 193, 205–224. doi:10.1016/j.ecolmodel.2005.07.023

Chen, D., Liu, Z., Luo, Z., Webber, M., Chen, J., 2016. Bibliometric and visualized analysis of emergy research. Ecol. Eng. 90, 285–293. doi:10.1016/j.ecoleng.2016.01.026

Chen, W., Liu, W., Geng, Y., Brown, M.T., Gao, C., Wu, R., 2017. Recent progress on emergy research: A bibliometric analysis. Renew. Sustain. Energy Rev. 73, 1051–1060. doi:10.1016/j.rser.2017.02.041

Cheng, H., Chen, C., Wu, S., Mirza, Z.A., Liu, Z., 2017. Emergy evaluation of cropping, poultry rearing, and fish raising systems in the drawdown zone of Three Gorges Reservoir of China. J. Clean. Prod. 144, 559–571. doi:10.1016/j.jclepro.2016.12.053

FAO, 2016. The State of World Fisheries and Aquaculture. FAO, Rome, 200 pp.

Fezzardi, D., Massa, F., Avila Zaragoza, P., Rad, F., Yücel-Gier, G., Deniz, H., Hadj Ali Salem, M., Hamza, H.A., Ben Salem, S., 2013. Indicators for sustainable aquaculture in Mediterranean and Black sea countries. Guide for the use of indicators to monitor sustainable development of aquaculture, GFCM. Studies and Reviews. doi:10.1017/CBO9781107415324.004

Fry, J.P., Love, D.C., MacDonald, G.K., West, P.C., Engstrom, P.M., Nachman, K.E., Lawrence, R.S., 2016. Environmental health impacts of feeding crops to farmed fish. Environ. Int. 91, 201–214. doi:10.1016/j.envint.2016.02.022

Garcia, F., Kimpara, J.M., 2012. Aquicultura e Sustentabilidade - Parte 2. Pesqui. Tecnol.

Garcia, F., Kimpara, J.M., Valenti, W.C., Ambrosio, L.A., 2014. Emergy assessment of tilapia cage farming in a hydroelectric reservoir. Ecol. Eng. 68, 72–79. doi:10.1016/j.ecoleng.2014.03.076

Glavic, P., Lukman, R., 2007. Review of sustainability terms and their definitions 15, 1875–1885. doi:10.1016/j.jclepro.2006.12.006

Han, D., Chen, Y., Zhang, C., Ren, Y., Xue, Y., Wan, R., 2017. Evaluating impacts of intensive shellfish aquaculture on a semi-closed marine ecosystem. Ecol. Modell. 359, 193–200. doi:10.1016/j.ecolmodel.2017.05.024

Hau, J.L., Bakshi, B.R., 2004. Promise and problems of emergy analysis. Ecol. Modell. 178, 215–225. doi:10.1016/j.ecolmodel.2003.12.016

Henriksson, P.J.G., Tran, N., Mohan, C.V., Chan, C.Y., Rodriguez, U.P., Suri, S., Mateos, L.D., Utomo, N.B.P., Hall, S., Phillips, M.J., 2017. Indonesian aquaculture futures – Evaluating environmental and socioeconomic potentials and limitations. J. Clean. Prod. 162, 1482–1490. doi:10.1016/j.jclepro.2017.06.133

Huang, S., 1998. Urban ecosystems, energetic hierarchies, and ecological. J. Environ. Manage. 39–51.

Johnston, P., Everard, M., Santillo, D., Robert, K.H., 2007. Reclaiming the definition of sustainability. Environ. Sci. Pollut. Res. 14, 60–66.

Kimpara, J.M., Zadjband, A.D., Valenti, W.C., 2012. Métodos para medir a sustentabilidade na aquicultura. Embrapa Meio-Norte.

Lei, K., Wang, Z., Ton, S.S., 2008. Holistic emergy analysis of Macao. Ecol. Eng. 32, 30–43. doi:10.1016/j.ecoleng.2007.08.008

Lemasson, A.J., Fletcher, S., Hall-Spencer, J.M., Knights, A.M., 2017. Linking the biological impacts of ocean acidification on oysters to changes in ecosystem services: A review. J. Exp. Mar. Bio. Ecol. 492, 49–62. doi:10.1016/j.jembe.2017.01.019

Li, D., Wang, R., 2009. Hybrid Emergy-LCA (HEML) based metabolic evaluation of urban residential areas: The case of Beijing, China. Ecol. Complex. 6, 484–493. doi:10.1016/j.ecocom.2009.09.002

Li, L., Lu, H., Ren, H., Kang, W., Chen, F., 2011. Emergy evaluations of three aquaculture systems on wetlands surrounding the Pearl River Estuary, China. Ecol. Indic. 11, 526–534. doi:10.1016/j.ecolind.2010.07.008

Liang, H., Ren, J., Dong, L., Gao, Z., 2016. Is the hydrogen production from biomass technology really sustainable? Answer by life cycle emergy analysis. Int. J. Hydrogen Energy 41, 10507–10514. doi:10.1016/j.ijhydene.2016.04.082

Lima, J.S.G., Rivera, E.C., Focken, U., 2012. Emergy evaluation of organic and conventional marine shrimp farms in Guaraira Lagoon, Brazil. J. Clean. Prod. 35, 194–202. doi:10.1016/j.jclepro.2012.05.009

Liu, G.Y., Yang, Z.F., Chen, B., Zhang, Y., Zhang, L.X., Zhao, Y.W., Jiang, M.M., 2009. Emergy-based urban ecosystem health assessment: A case study of Baotou, China. Commun. nonlinear Sci. Numer. Simul. 14, 972–981. doi:10.1016/j.cnsns.2007.09.017

McDonough, S., Gallardo, W., Berg, H., Trai, N. V., Yen, N.Q., 2014. Wetland ecosystem service values and shrimp aquaculture relationships in Can Gio, Vietnam. Ecol. Indic. 46, 201–213. doi:10.1016/j.ecolind.2014.06.012

Moura, R.S.T., Valenti, W.C., Henry-Silva, G.G., 2016. Sustainability of Nile tilapia net-cage culture in a reservoir in a semi-arid region. Ecol. Indic. 66, 574–582. doi:10.1016/j.ecolind.2016.01.052

Nhu, T.T., Schaubroeck, T., Henriksson, P.J.G., Bosma, R., Sorgeloos, P., Dewulf, J., 2016. Environmental impact of non-certified versus certified (ASC) intensive Pangasius aquaculture in Vietnam, a comparison based on a statistically supported LCA. Environ. Pollut. 219, 156–165. doi:10.1016/j.envpol.2016.10.006

Odum, H.T., 1996. Environmental Accounting. Emergy and Environmental Decision Making. John Wiley & Sons, Inc.

Odum, H.T., 2000. Emergy evaluation of salmon pen culture. Int. Inst. Fish. Econ. Trade 2000 Proc. 1–8.

Ortega, E., Zanghetin, M., Takahashi, F., 2008. Como funciona la naturaleza - enfoque sistemas. Laboratório Eng. Ecológica da Unicamp.

Ottinger, M., Clauss, K., Kuenzer, C., 2016. Aquaculture: Relevance, distribution, impacts and spatial assessments - A review. Ocean Coast. Manag. 119, 244–266. doi:10.1016/j.ocecoaman.2015.10.015

Pulselli, R.M., 2010. Integrating emergy evaluation and geographic information systems for monitoring resource use in the Abruzzo region (Italy). J. Environ. Manage. 91, 2349–2357. doi:10.1016/j.jenvman.2010.06.021

Read, P., Fernandes, T., 2003. Management of environmental impacts of marine aquaculture in Europe. Aquaculture 226, 139–163. doi:10.1016/S0044-8486(03)00474-5

Shi, H., Zheng, W., Zhang, X., Zhu, M., Ding, D., 2013. Ecological-economic assessment of monoculture and integrated multi-trophic aquaculture in Sanggou Bay of China. Aquaculture 410–411, 172–178. doi:10.1016/j.aquaculture.2013.06.033

Siche, R., Pereira, L., Agostinho, F., Ortega, E., 2010. Convergence of ecological footprint and emergy analysis as a sustainability indicator of countries: Peru as case study. Commun. Nonlinear Sci. Numer. Simul. 15, 3182–3192. doi:10.1016/j.cnsns.2009.10.027

Travaini-Lima, F., Sipaúba-Tavares, L.H., 2012. Efficiency of a constructed wetland for wastewaters treatment. Acta Limnol. Bras. 24, 255–265. doi:10.1590/S2179-975X2012005000043

Valenti, W.C., Kimpara, J.M., Preto, B.D.L., 2011. Measuring aquaculture sustainability. World Aquac. 42, 26–30.

Valenti, W.C.; Kimpara, J.M.; Zajdjband, A.D., 2010. Métodos para medir a sustentabilidade na aquicultura. Panorama da Aquicultura. 20, 28-33

Vassallo, P., Bastianoni, S., Beiso, I., Ridolfi, R., Fabiano, M., 2007. Emergy analysis for the environmental sustainability of an inshore fish farming system. Ecol. Indic. 7, 290–298. doi:10.1016/j.ecolind.2006.02.003

Vassallo, P., Beiso, I., Bastianoni, S., Fabiano, M., 2009. Dynamic emergy evaluation of a fish farm rearing process. J. Environ. Manage. 90, 2699–2708. doi:10.1016/j.jenvman.2009.02.013

Villasante, S., Rivero Rodríguez, S., Molares, Y., Martínez, M., Remiro, J., García-Díez, C., Lahoz, C., Omar, I., Bechardas, M., Elago, P., Ekandjo, M., Saisai, M., Awity, L., 2015. Are provisioning ecosystem services from rural aquaculture contributing to reduce hunger in Africa? Ecosyst. Serv. 16, 365–377. doi:10.1016/j.ecoser.2015.07.003

Walton, M.E.M., Vilas, C., Cañavate, J.P., Gonzalez-Ortegon, E., Prieto, A., van Bergeijk, S.A., Green, A.J., Librero, M., Mazuelos, N., Le Vay, L., 2015. A model for the future: Ecosystem services provided by the aquaculture activities of Veta la Palma, Southern Spain. Aquaculture 448, 382–390. doi:10.1016/j.aquaculture.2015.06.017

Wang, G., Dong, S., Tian, X., Gao, Q., Wang, F., 2015. Sustainability evaluation of different systems for sea cucumber (*Apostichopus japonicus*) farming based on emergy theory. J. Ocean Univ. China 14, 503–510. doi:10.1007/s11802-015-2453-z

Wilfart, A., Prudhomme, J., Blancheton, J., Aubin, J., 2013. LCA and emergy accounting of aquaculture systems: Towards ecological intensification. J. Environ. Manage. 121, 96–109. doi:10.1016/j.jenvman.2013.01.031

Williamson, T.R., Tilley, D.R., Campbell, E., 2015. Emergy analysis to evaluate the sustainability of two oyster aquaculture systems in the Chesapeake Bay. Ecol. Eng. 85, 103–120. doi:10.1016/j.ecoleng.2015.09.052

Zhang, L.X., Song, B., Chen, B., 2012. Emergy-based analysis of four farming systems: insight into agricultural diversification in rural China. J. Clean. Prod. 28, 33–44. doi:10.1016/j.jclepro.2011.10.042

Zhang, L.X., Ulgiati, S., Yang, Z.F., Chen, B., 2011. Emergy evaluation and economic analysis of three wetland fish farming systems in Nansi Lake area, China. J. Environ. Manage. 92, 683–694. doi:10.1016/j.jenvman.2010.10.005

Zhao, S., Song, K., Gui, F., Cai, H., Jin, W., Wu, C., 2013. The emergy ecological footprint for small fish farm in China. Ecol. Indic. 29, 62–67. doi:10.1016/j.ecolind.2012.12.009