Caribbean Journal of Science, Vol. 46, No. 1, 12-18, 2010

Indicator Taxa to Assess Anthropogenic Impacts in Caribbean and Bahamas Tidal Creeks

Craig A. Layman[1], D. Albrey Arrington[2], Philip A. Kramer[3], Lori Valentine-Rose[4], and Craig P. Dahlgren[5]

[1]*Marines Sciences Program, Department of Biological Sciences, Florida International University, 3000 NE 151st St, North Miami, FL 33181, USA*
[2]*Loxahatchee River District, 2500 Jupiter Park Drive, Jupiter, FL 33458-8964, USA*
[3]*The Nature Conservancy, 55 N. Johnson Road, Sugarloaf Key, FL 33042, USA*
[4]*1415 Berry Dr, Cleburne, TX, 76033, USA*
[5]*Perry Institute for Marine Science, 100 North US Hwy 1, Suite 202, Jupiter, Florida 33477-5112, USA*
Corresponding author: Craig Layman, Marines Sciences Program, Department of Biological Sciences, Florida International University, 3000 NE 151st St, North Miami, FL 33181, USA; email - cal1634@yahoo.com; phone - 305 919 4000.

Abstract.—**Mangrove wetlands are being altered by human impacts throughout the Caribbean and Bahamas at an alarming rate. There is a pressing need for a set of criteria that can be used to identify the degree of anthropogenic impact, as well as to identify those areas most suitable for conservation and/or restoration initiatives. We provide a set of taxa that can be used as indicators in mangrove-dominated tidal creek ecosystems. The analysis was based on gradients of human impact measured at both local (tidal creek fragmentation) and regional (human threat indices) spatial scales. Such indicator taxa provide a simple tool for local resource managers, policy makers, and educators, and can be used for rapid assessments of human impacts on floral and faunal assemblages in tidal creeks.**

Keywords.—**Connectivity, corridor, ecosystem fragmentation, fish, Index of Biotic Integrity, mangrove, nursery, ontogenetic migration**

With more than 116 million people living within 100 km of Caribbean coastal regions (Burke and Maidens 2004), anthropogenic stressors to the coastal realm are severe, widespread, and on-going. There is a distinct need for tools to assess the current status of shallow-water coastal ecosystems, set conservation and restoration priorities, and evaluate the success of management efforts. Mangroves are among the most threatened coastal biotypes (Hamilton and Snedaker 1984; Ong 1995; Ellison and Farnsworth 1996; Valiela et al. 2001; Faunce and Serafy 2006), yet metrics to assess their relative "health" (*sensu* Rapport et al. 1998) are largely lacking. This is problematic because mangroves are integral components of the interconnected "back-reef" environment (Adams et al. 2006), and there is increasing evidence that they are critical to maintain ecosystem function in adjacent marine habitats such as coral reefs (Mumby et al. 2003; Mumby and Hastings 2008). For example, mangrove habitats serve as nursery habitats for many reef-associated species (Nagelkerken et al. 2000; Layman et al. 2004; Valentine-Rose et al. 2007b), including socio-economically important species such as Nassau grouper (*Epinephelus striatus* Bloch) (Dahlgren and Eggleston 2000; Dahlgren and Eggleston 2001) and spiny lobster (*Panulirus argus* Latreille) (Acosta and Butler 1997).

Floral and faunal assemblage composition can be a useful measure of anthropogenic impacts in aquatic systems because constituent plants and animals reflect the integrated physical and biological processes operating at a given site (Karr and Chu 1999). When applying a biologically-based indicator system, there are inherent trade-offs between the specificity of information sought and the difficulty of implementing the approach. For example, sampling protocols that require precise quantification of multiple metrics can provide significant power to distinguish among sites with varying degrees of anthropogenic impact. One widely accepted approach is the Index of Biotic Integrity (IBI), a system of metrics that incorporates biological and ecological information from individual-, population- and community-levels into a single index of system quality (Karr 1981; Karr and Chu 1999).

Although a powerful approach, metrics composing an IBI (e.g., % of individuals that are members of certain feeding guilds or % of individuals with a disease) may require substantial scientific expertise and involve techniques that are relatively time consuming and expensive. In certain situations, a simple set of indicator taxa may be preferred. An index based solely on presence/absence of individuals from general taxonomic groupings may sacrifice discriminatory power, but would be accessible for non-scientist stakeholders. For example, "parataxonomists", i.e., local assistants trained by professional biologists (Basset et al. 2004), have played an important role in the conservation of terrestrial ecosystems, and especially with efforts to document and catalogue tropical biodiversity (Goldstein 2004; Janzen 2004). Similarly, a biologically-based monitoring system amenable to parataxonomists would facilitate local conservation and management strategies in aquatic ecosystems. In this study, we evaluated a suite of indicator taxa that can be identified easily by parataxonomists, and can be used as a means to assess anthropogenic impacts in mangrove-dominated tidal wetlands on Caribbean and Bahamian Islands, systems locally referred to as "tidal creeks".

Floral and faunal surveys were conducted in mangrove-dominated tidal creeks located in the U.S. Virgin Islands (St. Croix, St. John, St. Thomas) and Bahamas (Andros and New Providence Islands). Site characteristics varied substantially, but most creeks had a somewhat constricted mouth that opened to a broad, shallow wetland. All surveyed sites were associated with low-lying coastal areas with relatively small watersheds. Such systems are dominated by tidal exchange and not freshwater input. Examples of recent studies that have been conducted in similar systems include Dahlgren and Eggleston (2001), Layman et al. (2007), Valentine-Rose et al. (2007b), and Rypel and Layman (2008).

Based on previous work (Layman and Silliman 2002; Layman et al. 2004; Valentine-Rose et al. 2007a), we *a priori* identified taxa that could serve as indicators of creek health (Table 1). Two criteria were used to identify taxa. First, we based groupings at taxonomic levels that would be relatively easy for parataxonomists to identify. For example, whereas sponges are often difficult to identify to species, identifying an organism as a "sponge" is less problematic. This approach yielded indicator groupings at taxonomic levels from species to phylum. Second, we attempted to select taxa that would provide insight into the degree of habitat degradation. That is, we avoided selecting taxa abundant in creeks regardless of the degree of degradation (e.g., the macroalgae *Batophora oerstedi*), and omitted taxa that are so rare that their non-occurrence would not necessarily be indicative of anthropogenic impact (e.g., tiger grouper *Mycteroperca tigris*).

Two independent measures of anthropogenic impact provided the context to evaluate indicator taxa: a regional approach based on anthropogenic "threat" measures (Burke and Maidens 2004), as well as a site-specific index based on degree of creek fragmentation (Layman et al. 2004). The regional measure was based on the "Reefs at Risk" database, an integrated quantification of the degree of human impacts (termed "threats") to coastal ecosystems throughout the Caribbean (Burke and Maidens 2004). More than 30 physical and socioeconomic data sources were used for the Reefs at Risk analyses, including data on land cover, elevation, bathymetry, population distribution and growth rates, and location of cities, ports, and other infrastructure. For ease of interpretation, each areal unit was rated as "low", "medium", or "high" threat for each of four individual threat categories: coastal development, sediment and pollution from inland sources, marine-based sources of pollution, and over-fishing. The ratings for the four categories were then combined to yield a single overall threat index. The index is set to the highest threat value (low, medium, or high) recorded for any individual threat, with two further modifications: the integrated index is designated as "very

TABLE 1. Taxonomic groupings identified *a priori* as potential indicators of creek health. Visual surveys at each site were used to record the presence or absence of each of these taxa in each surveyed transect. Positive indicators (+) signify the taxon was more likely to be found in less impacted sites (lower regional threat index or less degree of fragmentation), and negative indicators (–) were more frequently found in the more degraded sites. Organisms are listed at a broad taxonomic classification (i.e., to phylum or genus, rarely to the species-level) to allow for relative ease of identification.

Common Name	Scientific Classification	Positive/Negative
Anchovy, Herring, or Silverside	Family Engraulididae, Clupeidae, and Atherinidae	+
Angelfish	*Holacanthus* spp. and *Pomacanthus* spp.	+
Barnacle	Subclass Cirripedia	+
Barracuda	*Sphyraena barracuda* Walbaum	+
Blue Crab	*Callinectes sapidus* Rathbun	+
Butterflyfish	*Chaetodon* spp.	+
Checkered Puffer	*Sphoeroides testudineus* Linnaeus	+
Coral	Class Hydrozoa and Class Anthozoa	+
Damselfish (other than Sergeant Major)	*Stegastes* spp.	+
Filamentous Green Algae	*Chaetomorpha* spp. and *Enteropmorpha* spp.	–
Grouper	*Epinephelus* spp.	+
Grunt	*Haemulon* spp.	+
Halimeda spp. Macroalgae	*Halimeda* spp.	+
Jack	Family Carangidae	+
Mojarra	*Eucinostomus* spp. and *Gerres cinereus* Walbaum	+
Mosquitofish	*Gambusia* spp.	–
Oyster	*Isognomon alatus* Gmelin	+
Parrotfish	Scaridae spp.	+
Queen Conch	*Strombus gigas* Linnaeus	+
Sea Anemone	Orders Actiniaria and Ceriantharia	+
Sergeant Major	*Abudefduf saxatilis* Linnaeus	+
Sheepshead Minnow	*Cypronodon variegatus* Lacépède	–
Snapper (Other than Yellowtail)	*Lutjanus griseus* Linnaeus or *L. apodus* Walbaum	+
Sponge	Phylum Porifera	+
Surgeonfish or Doctorfish	*Acanthurus bahianus* Castelnau or *A. chirurgus* Bloch	+
Turtle Grass	*Thallasia testudinum* Banks *ex* König	+
Wrasse	*Halichoeres* spp. or *Thalassoma bifasciatum* Bloch	+
Yellowtail Snapper	*Ocyurus chrysurus* Bloch	+

high" in areas where at least three individual threats were rated as "high", and the integrated index is set to "high" in areas where at least three threats were rated as "medium," (Burke and Maidens 2004).

Our site-specific example was based on degree of creek fragmentation following Layman et al. (2004). Each tidal creek was classified as totally fragmented, partially fragmented, minimally fragmented, or unfragmented. *Totally fragmented* systems are those in which surface water connectivity from the ocean does not extend to upper portions of the creek (e.g., due to road construction) resulting in a relatively isolated wetland upstream of the blockage (see Layman et al. 2007; Valentine-Rose et al. 2007a). In *partially fragmented* systems some surface water connectivity remains to upstream areas (e.g., through culverts). In *minimally fragmented* systems the majority of surface water connectivity remains (i.e., through bridges), and *unfragmented* systems have unimpeded surface water connectivity throughout the creek.

In tropical and subtropical marine ecosystems, water clarity allows aquatic fauna to be assessed in a non-destructive manner using underwater visual census (UVC). This technique, first developed by Brock (1954), has become standard methodology for assessing occurrence of organisms in tropical estuarine and marine habitats. We conducted 100m x 2m transect surveys along the mangrove fringe of creeks using snorkeling gear. Each transect survey lasted

~20 minutes, a survey rate of ~5m/minute. In some sites (typically totally fragmented systems), snorkeling was precluded by shallow water depths and surveys were conducted by walking along the mangrove fringe. Two areas in creeks were surveyed, one at the creek mouth and one upstream. In small systems (<~5 hectares), mouth surveys were taken at a random 100m section within 500m of the confluence of the tidal system with marine waters. In large systems (>~5 hectares), the mouth survey was conducted at a random 100m section 0.5-1.0km from the confluence with marine waters. Upstream survey sites were chosen at random locations approximately ½ of the distance between the creek mouth and the most inland extent of the creek system. We surveyed all systems that could be readily accessed on our focal islands. Each survey was considered as an individual data point in the analysis, so that some sites have both an upstream and downstream site which were considered separately.

For each indicator taxa, we used logistic regression to assess the probability of occurrence (i.e., presence) for each taxa as a function of the regional threat index from the Reefs at Risk database. We then conducted a separate analysis based on the fragmentation index, with categorical measures (i.e., totally fragmented sites = 3, partially fragmented sites = 2, etc.) serving as the independent variable. In the logistic regression analyses, presence of an indicator taxa in a survey was assigned a value of "1" and absence a "0". We evaluated the significance of the relationships (i.e., human impact level vs. presence/absence) at the 0.05 level using the log-likelihood ratio test.

We conducted 97 surveys in creeks ($n = 57$) that ranged across all levels of the regional and site-specific measures of anthropogenic impact. Occurrence of 16 taxa correlated significantly with the fragmentation index, and 7 taxa were correlated significantly with the regional threat index (Table 2). All taxa that correlated significantly with the regional

TABLE 2. Results of logistic regression analyses between occurrence of taxa and the two anthropogenic impact indices: (A) fragmentation and (B) regional threat.

(A) Fragmentation Index:		
Taxonomic Grouping	Log-Likelihood Ratio	P
Sponge	33.8	<0.001
Grunt	29.4	<0.001
Barnacle	26.9	<0.001
Parrotfish	25.2	<0.001
Turtle Grass	22.8	<0.001
Sergeant Major	21.0	<0.001
Halimeda spp. Macroalgae	19.1	<0.001
Snapper (other than Yellowtail)	18.5	<0.001
Sheepshead Minnow	17.5	<0.001
Barracuda	15.4	<0.001
Wrasse	13.3	<0.001
Mojarra	10.0	0.002
Coral	9.6	0.002
Mosquitofish	9.0	0.003
Damselfish (other than Sergeant Major)	8.7	0.003
Checkered puffer	8.4	0.004
(B) Regional Threat Index:		
Taxonomic Grouping	Log-Likelihood Ratio	P
Turtle Grass	21.9	<0.001
Sponge	17.4	<0.001
Coral	14.3	<0.001
Sergeant Major	8.5	0.004
Halimeda spp. Macroalgae	7.9	0.005
Wrasse	5.0	0.03
Damselfish (other than Sergeant Major)	4.9	0.03

threat index also correlated significantly with the fragmentation index. Taxa correlated with the regional threat index tended to be species that were relatively sedentary, including plants, immobile invertebrates, and demersal fishes. Taxa correlated with the fragmentation index represented diverse taxonomic, trophic, body size, and motility characterizations. Examples of indicator taxa correlated with both regional and local impact indexes are pictured in Fig. 1.

Taxa presence/absence patterns across the two human impact gradients likely reflect a diverse suite of underlying community- and ecosystem-level factors (Layman et al. 2007; Valentine-Rose et al. 2007a). For example, fragmentation of tidal creeks affects constituent biota through at least four mechanisms. First, fragmentation disrupts metapopulation dynamics, thereby reducing the supply of larvae, juveniles, and adults to fragmented areas (Gonzalez *et al.* 1998; Pringle 2006). Second, overall ecosystem size (volume of water and/or surface area of inudated wetland) is reduced due to increased sedimentation following a reduction in water velocity. Third, variation in physico-chemical conditions increases, especially in temperature and salinity, because of the lack of tidal flushing. And fourth, partially due to each of the preceding factors, there is an overall decline in abundance of structural flora (e.g., seagrasses and macroalgae) that provide important habitat for other organisms (Adams et al. 2006).

Despite the great variability in site characteristics among surveyed creeks (e.g., in depth, current velocity, habitat availability, etc.), patterns were sufficiently consistent to identify a suite of taxa whose presence or absence was correlated with *a priori* characterizations of human impacts. Thus, despite the myriad ways that humans affect coastal ecosystems, there may be some general similarities in impacts to local biota across impact gradients. More consistent results (i.e., more significantly correlated indicator taxa) for the localized index reflects the fact that human impacts can best be categorized at a site-specific scale. For example, a given tidal creek can be significantly more or less degraded within a regional classification depending on local factors. Yet it is promising for regional-scale conservation efforts that some taxa may indeed indicate regional scale phenomena.

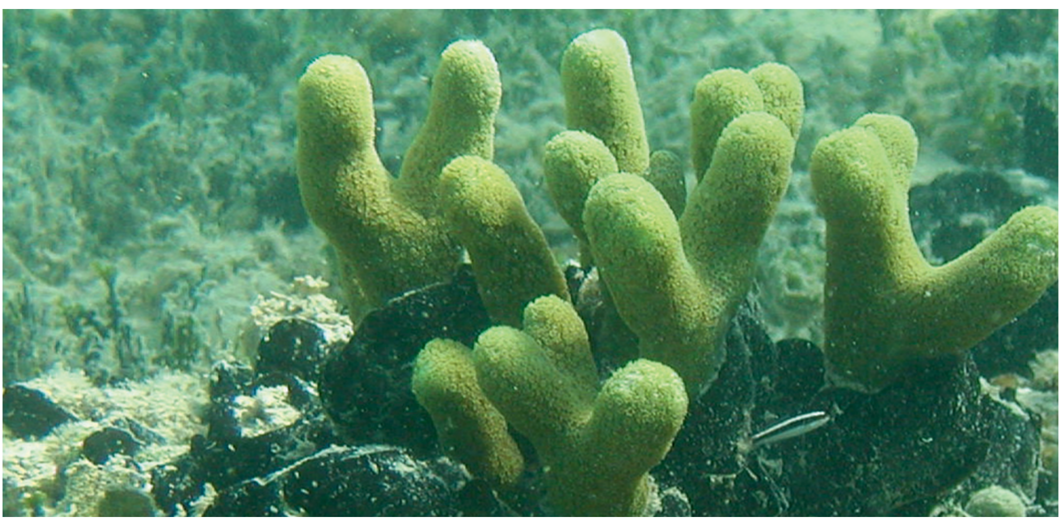

FIG. 1. Four of the indicator taxa found to correlate significantly with both regional threat and local human impact indices: coral, sponge (around base of coral), wrasse (bottom right), and *Halimeda* spp. (left background). Organisms are listed at a broad taxonomic classification (i.e., to phylum or genus, rarely to the species-level) to allow for relative ease of identification.

Presence/absence of particular taxa alone cannot be used to elucidate mechanisms that give rise to the emergent floral and faunal assemblages. Yet indicator species have been used to help guide conservation efforts in a wide variety of ecosystems (e.g., Lindenmayer et al. 2000; Roth and Weber 2008), and we believe the indicator taxa presented herein represent one useful tool in developing conservation strategies in Caribbean and Bahamas coastal ecosystems. The system proposed herein can be immediately applied to assess ecosystems in the areas examined as part of this study. In areas that differ substantially in abiotic (e.g., freshwater input or water depth) or biotic (e.g., a different biogeographic region) factors, we encourage researchers to identify other indicator species that reflect human impacts. Detailed study of coastal ecosystems and how they are impacted by human activities are direly needed. Contributions by parataxonomists using indicator taxa can be one critical component of conservation, restoration, and management efforts at both local and regional scales.

Acknowledgements.—This work was supported by an RJ Kose grant through The Nature Conservancy, the Acorn Alcinda Foundation, the Donnelley Environmental Fellowship at Yale University and NSF DGE#0319143 and OCE#0746164. The Bahamas Environmental Research Center, The College of the Bahamas, and The Nature Conservancy offices in The Bahamas and the U.S. Virgin Islands provided logistical support.

Literature Cited

Acosta C. A. and M. J. Butler. 1997. Role of mangrove habitat as a nursery for juvenile spiny lobster, *Panulirus argus*, in Belize. *Mar. Fresh. Res.* 48: 721-727.

Adams A. J., C. P. Dahlgren, G. T. Kellison, M. S. Kendall, C. A. Layman, J. A. Ley, I. Nagelkerken and J. E. Serafy. 2006. Nursery function of tropical back-reef systems. *Mar. Ecol. Prog. Ser.* 318: 287-301.

Basset Y., V. Novotny, S. E. Miller, G. D. Weiblen, O. Missa and A. J. A. Stewart. 2004. Conservation and biological monitoring of tropical forests: the role of parataxonomists. *J. Appl. Ecol.* 41:163-174.

Brock V. E. 1954. A preliminary report on a method of estimating reef fish populations. *J. Wildlife Manage.* 18:297-308.

Burke L. and J. Maidens. 2004. *Reefs at Risk in the Caribbean, World Resources Institute*, Washington DC.

Dahlgren C. P. and D. B. Eggleston. 2000. Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. *Ecology*. 81:2227-2240.

Dahlgren C. P. and D. B. Eggleston. 2001. Spatiotemporal variability in abundance, size, and microhabitat associations of early juvenile Nassau grouper *Epinephelus striatus* in an off-reef nursery system. *Mar. Ecol. Prog. Ser.* 217:145-156.

Ellison A. M. and E. J. Farnsworth. 1996. Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends, and future predictions. *Biotropica*. 28:549-565.

Faunce C. H. and J. E. Serafy. 2006. Mangroves as fish habitat: 50 years of field studies. *Marine Ecology-Progress Series*. 318:1-18.

Goldstein P. Z. 2004. Systematic collection data in North American invertebrate conservation and monitoring programmes. *J. Appl. Ecol.* 41: 175-180.

Gonzalez A., J. H. Lawton, F. S. Gilbert, T. M. Blackburn and I. Evans-Freke. 1998. Metapopulation dynamics, abundance, and distribution in a microecosystem. *Science*. 281:2045-2047.

Hamilton L. S. and S. C. Snedaker. (eds.) 1984. *Handbook for mangrove area management*. UNEP, Gland.

Janzen D. H. 2004. Setting up tropical biodiversity for conservation through non-damaging use: participation by parataxonomists. *J. Appl. Ecol.* 41: 181-187.

Karr J. R. 1981. Assessment of biotic integrity using fish communities. *Fisheries*. 6:21-27.

Karr J. R. and E. W. Chu. 1999. *Restoring Life in Running Waters*. Island Press, Washington D. C.

Layman C. A., D. A. Arrington, R. B. Langerhans and B. R. Silliman. 2004. Degree of fragmentation affects fish assemblage structure in Andros Island (Bahamas) estuaries. *Caribbean J. Sci.* 40: 232-244.

Layman C. A., J. P. Quattrochi, C. M. Peyer and J. E. Allgeier. 2007. Niche width collapse in a resilient top predator following ecosystem fragmentation. *Ecol. Lett.* 10:937-944.

Layman C. A. and B. R. Silliman. 2002. Preliminary survey and diet analysis of juvenile fishes of an estuarine creek on Andros Island, Bahamas. *Bull. Mar. Sci.* 70:199-210.

Lindenmayer D. B., C. R. Margules and D. B. Botkin. 2000. Indicators of biodiversity for ecologically sustainable forest management *Conservation Biology*. 14:941-950.

Mumby P. J., A. J. Edwards, J. E. Arias-Gonzalez, K. C. Lindeman, A. Blackwell, A. Gall, M. I. Gorczynska, A. R. Harborne, C. L. Pescod, H. Renken, C. C. C. Wabnitz and G. Llewellyn. 2003. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature*. 423:280-283.

Mumby P. J. and A. Hastings. 2008. The impact of ecosystem connectivity on coral reef resilience. *J. Appl. Ecol.* 45:854-862.

Nagelkerken I., G. van der Velde, M. W. Gorissen, G. J. Meijer, T. van't Hof and C. den Hartog. 2000. Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Est. Coast. Shelf Sci.* 51:31-44.

Ong J. E. 1995. The ecology of mangrove conservation and management. *Hydrobiologia*. 295:343-351.

Pringle C. 2006. Hydrologic connectivity: a neglected dimension of conservation biology. In: Connectivity Conservation (eds Crooks KR and Sanjayan M). Cambridge University Press Cambridge, pp 233-254.

Rapport D. J., R. Costanza and A. J. McMicheal. 1998. Assessing ecosystem health. *Trends Ecol. Evol.* 13:397-402.

Roth T. and D. Weber. 2008. Top predators as indicators for species richness? Prey species are just as useful. *J. Appl. Ecol.* 45:987-991.

Rypel A. and C. A. Layman. 2008. Degree of aquatic ecosystem fragmentation predicts population characteristics of gray snapper (*Lutjanus grisues*) in Caribbean tidal creeks. *Can. J. Fish. Aquat. Sci.* 65:335-339.

Valentine-Rose L., J. A. Cherry, J. J. Culp, K. E. Perez, J. B. Pollock, D. A. Arrington and C. A. Layman. 2007a. Floral and faunal differences between fragmented and unfragmented Bahamian tidal creeks. *Wetlands*. 27:702-718.

Valentine-Rose L., C. A. Layman, D. A. Arrington and A. L. Rypel. 2007b. Habitat fragmentation affects fish secondary production in Bahamian tidal creeks. *Bull. Mar. Sci.* 80:863-878.

Valiela I., J. L. Bowen and J. K. York. 2001. Mangrove forests: One of the world's threatened major tropical environments. *Bioscience*. 51:807-815.