Marine Environmental Research 103 (2015) 95–102

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Isotopic studies in Pacific Panama mangrove estuaries reveal lack of effect of watershed deforestation on food webs

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ARTICLE INFO

Article history:
Received 13 July 2014
Received in revised form
17 October 2014
Accepted 24 October 2014
Available online 25 October 2014

Keywords:
Nitrogen
Carbon
Sulfur
Mixing models
Food webs

ABSTRACT

Stable isotopic N, C, and S in food webs of 8 mangrove estuaries on the Pacific coast of Panama were measured to 1) determine whether the degree of deforestation of tropical forests on the contributing watersheds was detectable within the estuarine food web, and 2) define external sources of the food webs within the mangrove estuaries. Even though terrestrial rain forest cover on the contributing watersheds differed between 23 and 92%, the effect of deforestation was not detectable on stable isotopic values in food webs present at the mouth of the receiving estuaries. We used stable isotopic measures to identify producers or organic sources that supported the estuarine food web. N isotopic values of consumers spanned a broad range, from about 2.7 to 12.3‰. Mean δ^{15}N of primary producers and organic matter varied from 3.3 for macroalgae to 4.7‰ for suspended particulate matter and large particulate matter. The δ^{13}C consumer data varied between −26 and −9‰, but isotopic values of the major apparent producers or organic matter sampled could not account for this range variability. The structure of the food web was clarified when we added literature isotopic values of microphytobenthos and coralline algae, suggesting that these, or other producers with similar isotopic signature, may be part of the food webs.

1. Introduction

Mangrove estuaries provide an important habitat for a high diversity of species (Nagelkerken et al., 2008). These estuaries are productive habitats that also support food webs, as they include substantial transfer of nutrients and organic matter among adjoined land-estuary-coastal ecosystems. Evidence for such couplings between contributing watersheds and estuaries has been inconsistent (Alongi, 2009). Some reports conclude that mangrove-derived materials subsidize coastal food webs (Dittmar and Lara, 2001a, b; Dittmar et al., 2001; Jennerjahn and Ittekot, 2002), while others do not (Schwamborn et al., 2002; Bouillon et al., 2004; Guest et al., 2004; Connolly et al., 2005; Kon et al., 2007). Stable isotopic studies of mangrove food webs suggest that secondary producers may depend less on imports from land, and on primary production by mangrove trees than on other primary producers (macroalgae, microphytobenthos, seagrasses, or detritus) (Hsieh et al., 2002; Kieckbusch et al., 2004). Allochtonous food sources (i.e. produced outside of the mangrove habitat) may also be used by consumers from the mangroves (e.g. Igulu et al., 2013). Generalizations are therefore difficult for a variety of reasons, including differences of primary producers and of consumers and in hydrodynamic conditions among different mangrove estuaries (Connolly et al., 2005; Nyunja et al., 2009; Vaslet et al., 2012).

One additional possible reason for contrasting results from one mangrove estuary to another may be that these tropical environments receive inputs from watersheds with rather different land covers. In many parts of the tropics, deforestation of watersheds has taken place (Valiela et al., 2013b). Deforestation creates significant differences in materials (water, sediment, nutrients) discharged to receiving waters (Valiela et al., 2013a,b), which raises the question about the possible effects on the food webs within the receiving mangrove estuaries.

The active transport and transformations of nutrients and suspended matter from the watershed to the estuaries pose the question whether food webs within the mangrove estuaries could be affected

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http://dx.doi.org/10.1016/j.marenvres.2014.10.003
0141-1136/

by watershed deforestation. This study focused on two questions. First, to assess the effect of watershed deforestation on food webs within the receving mangrove estuaries. Second, to identify the sources of N, C, and S that support the food webs present within the mangrove estuaries. For both lines of study, we use stable isotopes of nitrogen, carbon, and sulfur. We use $\delta^{13}C$ as a proxy for food web sources, $\delta^{15}N$ as a proxy for trophic level structure within the food webs, and both of them as an indicator of the effect of deforestation. $\delta^{34}S$ was used as an additional indicator of origin of food sources.

2. Material and methods

2.1. Study site

The study was conducted in mangrove ecosystems that received inputs from watersheds with different percentage of deforestation. These coupled watershed-mangrove ecosystems were located at the Gulf of Chiriquí, in the Pacific coast of Panama (Fig. 1). These eight coupled watershed-estuary systems were selected as they offered a range of conversions from forest to pasture land covers, with forest cover ranging between 23 and 92% (Table 1). They are first order streams carrying mostly baseline freshwater discharge (with surface runoff after large rainfall events) down-gradient through mangrove estuaries. The mangrove forests in this region extend between watersheds and the sea and include mangrove forests, which largely include C3 photosynthetic plants. Watersheds are dominated by red mangrove, *Rhizophora mangle*, and the piñuelo mangrove, *Pelliciera rhizophorae*, within the saltier reaches of the estuaries. Other less-abundant species also found in salty reaches include the black mangrove *Avicennia germinans*, and the white mangrove *Laguncularia racemosa*, as well as a variety of other species (Valiela et al. submitted). More details about geological setting, precipitation, and other information were provided in Valiela et al. (2012, 2013a,b).

2.2. Sampling design

To capture the variation of the influence of seasonal and inter-annual contrasts in stable isotopic signatures, sampling was carried out at the end of wet and dry seasons during the years 2009, 2010, and 2011. All samples were collected at the mouth of the eight selected estuaries, in sites with salinity ranging between 30 and 35. The main primary producers and pools of organic matter were sampled: mangrove trees, macroalgae, large particulate organic matter (POM), suspended particulate matter (SPM) and sediment.

Table 1
Selected properties of the watershed-estuary systems included in this study (Fig. 1).

Watershed-estuary	Area of watershed	Land cover (% of area)		
	(Ha)	Forest	Pasture	Other
Pixvae	1429	73	23	4
De la Mona	1575	47	47	6
Manglarito	239	91	6	3
Limón	665	92	5	3
Luis	1007	73	18	9
Salmonete	195	29	52	19
Chamuscado	2229	66	28	6
Grande	9639	23	43	34

2.2.1. Producers and organic matter

Primary producers sampled included mangrove trees (*R. mangle*, *P. rhizophorae*, and *A. germinans*) and macroalgae. Samples of 3–5 leaves of each mangrove species were combined to make one composite sample from each sampling site, and seasons of the different years. Obtained values of the three major mangrove species were pooled together. Samples of several species of brown and filamentous green macroalgae were collected at low tide from the surface of mangrove prop roots. Green and brown macroalgae data were also pooled together. Mangrove leaves and macroalgae samples were rinsed with double-distilled water, dried at 60 °C, ground to a fine powder, and stored at room temperature in glass vessels until analysis.

SPM and POM were sampled using different methods. To sample SPM, we sampled water from the well-mixed water columns within the mangrove estuaries. Water samples were collected in 20 L carboys and kept cool during transportation to the lab. SPM samples were obtained after passing the water through a

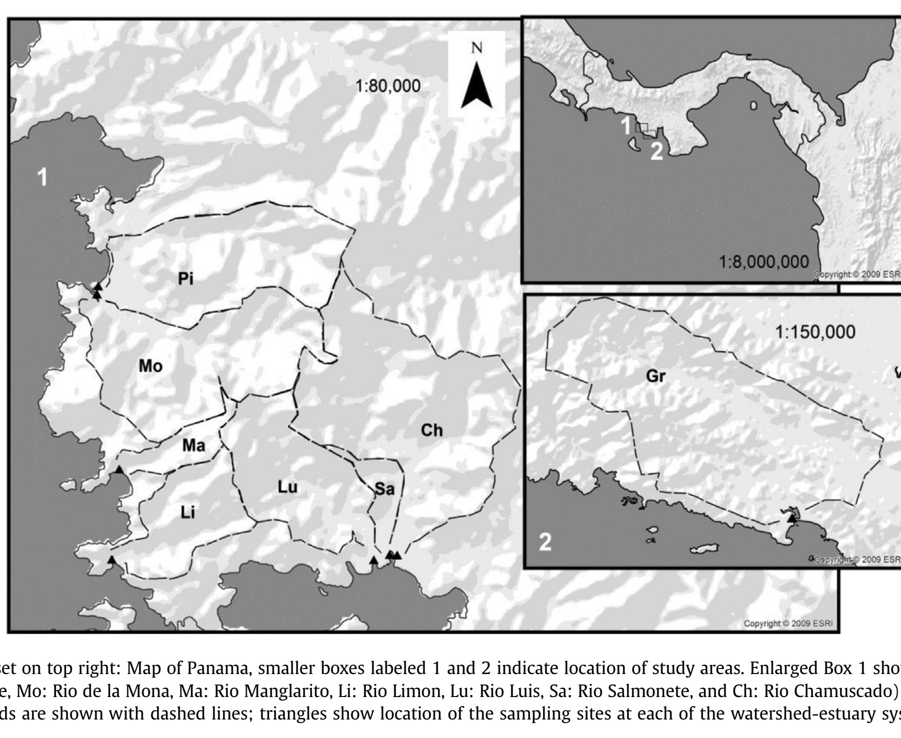

Fig. 1. Map of study areas. Inset on top right: Map of Panama, smaller boxes labeled 1 and 2 indicate location of study areas. Enlarged Box 1 shows location of seven watershed-estuary systems (Pi: Rio Pixvae, Mo: Rio de la Mona, Ma: Rio Manglarito, Li: Rio Limon, Lu: Rio Luis, Sa: Rio Salmonete, and Ch: Rio Chamuscado) and Box 2 shows location of Rio Grande (Gr). Watershed bounds are shown with dashed lines; triangles show location of the sampling sites at each of the watershed-estuary systems.