Available online at www.sciencedirect.com

ScienceDirect

Journal of Hydro-environment Research 11 (2016) 146–159

Journal of Hydro-environment Research

www.elsevier.com/locate/jher

Research papers

Surface and subsurface water coupled ecological model in a mangrove swamp, Ishigaki Island, Japan

Yoshihisa Akamatsu [a,*], Syunsuke Ikeda [b]

[a] *Division of Civil and Environmental Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube-shi, Yamaguchi 755-8611, Japan*
[b] *CTI Engineering Co., Ltd., 3-21-1, Nihonbashi Hama-cho, Chuo-ku, Tokyo 103-8430, Japan*

Received 14 July 2014; revised 4 March 2015; accepted 6 March 2015

Abstract

A surface and subsurface water coupled ecological model is presented to describe material cycling in a mangrove area, to which an ecosystem model is applied in order to account for chemical and biological reactions as well as physical processes. In this model, the nutrient transport from the groundwater to the river is estimated by the combined use of field measurements and numerical simulation of subsurface flow. The water movement and temporal variations in nutrient concentration obtained from the numerical simulation show a good agreement with the field observations, indicating that this model is valid for simulating material cycling in a mangrove area. The numerical simulation reveals that the supply of dissolved nutrients from the mangrove to the coastal area during spring tides is about 1.6 to 5.5 times larger than that during neap tides.

Keywords: Mangrove swamp; Material cycling; Ecological model; Groundwater flow

1. Introduction

Japan's mangrove ecosystems play a key role as habitat for various living organisms not only in mangrove area itself but also in the surrounding coastal areas of subtropical regions. Nutrient cycling is essential to maintain the mangrove ecosystem, and it is mainly controlled by physical processes occurring within the mangrove forest. Specifically, tidal motion within mangroves induces exchange of both water and nutrients with the open sea.

Wolanski et al. (1980) proposed a mathematical model for the movement of water and sediment in a tidal creek–mangrove swamp system. This model, which is a simple one-dimensional model taking into account the lateral water exchange, is able to reproduce the asymmetry between ebb and flood currents in mangroves. Aucan and Ridd (2000) indicated that most mangrove swamp/salt flat systems have ebb dominant tidal currents using a simple analytical model. Wolanski et al. (1990) applied a two-dimensional depth-averaged model to more reliably simulate the dynamic link between mangroves and coastal waters. Wu et al. (2001) refined an existing two-dimensional depth-integrated mathematical model to include both the effects of drag force induced by mangrove trees and the blockage effects on the mass fluxes through mangrove forests. This study revealed that the drag force induced by the mangrove trees and the blockage from the mangrove trees play an important role in the flow structure in a mangrove system.

In the view point of the material cycle, the material exchange between mangrove areas and surroundings has been studied in various field areas (Boto and Bunt, 1981; Dittmar and Lara, 2001; Mazda et al., 1990; Ridd et al., 1997; Twilley, 1985; Wattayakorn et al., 1990; Wolanski, 1992; Wolanski et al., 1990). In the mangrove area, litter yield and its transport have a great influence on the nutrient budget. Wafar et al. (1997) revealed that mangrove production is important mainly for the carbon budget of the estuaries and in sustaining the microbial food chain and nutrient regeneration, rather than the particulate food chain directly in a mangrove ecosystem fringing Mandovi–Zuari estuaries on the Central West Coast of India. The magnitude of the outwelling of particulate organic carbon (POC) increased during spring and autumn, consistent with the increase in the total litter production in a subtropical mangrove in Okinawa Island, South Japan (Mfilinge et al., 2005). These transports of litters and POC are induced by the water inundation and small creeks in the mangrove swamps. On the contrary, the groundwater flow has an important role in the transport of

* Corresponding author. Division of Civil and Environmental Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube-shi, Yamaguchi 755-8611, Japan. Tel.: +81-836-85-9342; fax: +81-836-85-9301.

E-mail address: yakamats@yamaguchi-u.ac.jp (Y. Akamatsu).

http://dx.doi.org/10.1016/j.jher.2015.03.005
1570-6443/

dissolved materials (Akamatsu et al., 2009; Ridd and Sam, 1996; Schwendenmann et al., 2006; Susilo et al., 2005; Wolanski and Gardiner, 1981). Makings et al. (2014) quantified the flux of inorganic and organic nutrients from groundwater to the estuary using field observations. However, quantitative discussions on groundwater flow are still limited, and these based on mathematical models are needed to reveal the groundwater effect on the material transport in the mangrove swamp.

Ecological models based on mass balance are useful methods to understand the mechanisms maintaining an aquatic ecosystem. Such ecological models for aquatic ecosystems are typically designed to be applied to enclosed water bodies such as bays and lakes. For example, coastal marine ecosystem simulation model (Kremer and Nixon, 1978), tidal flat estuary ecosystem simulation model (Baretta and Ruardij, 1988), Generalized Environmental Modeling System for Surfacewaters (GEMSS) (Na and Park, 2006), and Estuary, Lake and Coastal Ocean Model coupled with the Computational Aquatic Ecosystem DYnamics Model (ELCOM-CAEDYM) (Missaghi and Hondzo, 2010) are well-known water quality simulation models. These models usually consist of a surface flow model, a biological model, a heat-balance model and a mass-balance model. In these models, the interaction between surface and subsurface water is treated in a simple form, for example elution. However, they don't take into account the detailed mechanisms of the interaction between the surface and ground water.

In this study, a surface and subsurface water coupled ecological model was established to apply to the mangrove area in combination with detailed field observations. This model was designed to clarify the influence of subsurface water flux on the dissolved material exchange between the mangrove swamp and the main channel. The verification of this model using field observations and calculations for the spring and the neap tide were conducted in order to understand the influence of tidal conditions on the mass balance of dissolved nutrients in the mangrove ecosystem.

2. Materials and methods

2.1. Study area

The target area was the Nagura River on Ishigaki Island, Japan, which is situated at the western edge of the Ryukyu Islands chain close to Taiwan. The Nagura River has a length of 4.5 km, and a catchment area of 16.1 km^2 (Fig. 1(a)). The river possesses mangrove forests (the area is 0.16 km^2) near the river mouth and has a fairly large lagoon containing coral communities at the exit to the coastal zone (Fig. 1(b)). The dominant species of mangrove are *Bruguiera gymnorhiza* and *Rhizophora stylosa*. The field observations on the flow and water quality at Stations A, B and C were conducted in the previous study (Akamatsu et al., 2009). In this study, the observed results were utilized for the verification of a numerical model.

2.2. Field observation

Field observations were conducted over two separate periods: 20th July to 22th July, 2001 (TERM1) and 14th to 25th August, 2002 (TERM2). During the first period observations were conducted during spring tides to validate a numerical model. During the second period observations were made for numerical calculation of dissolved material cycling. Flow

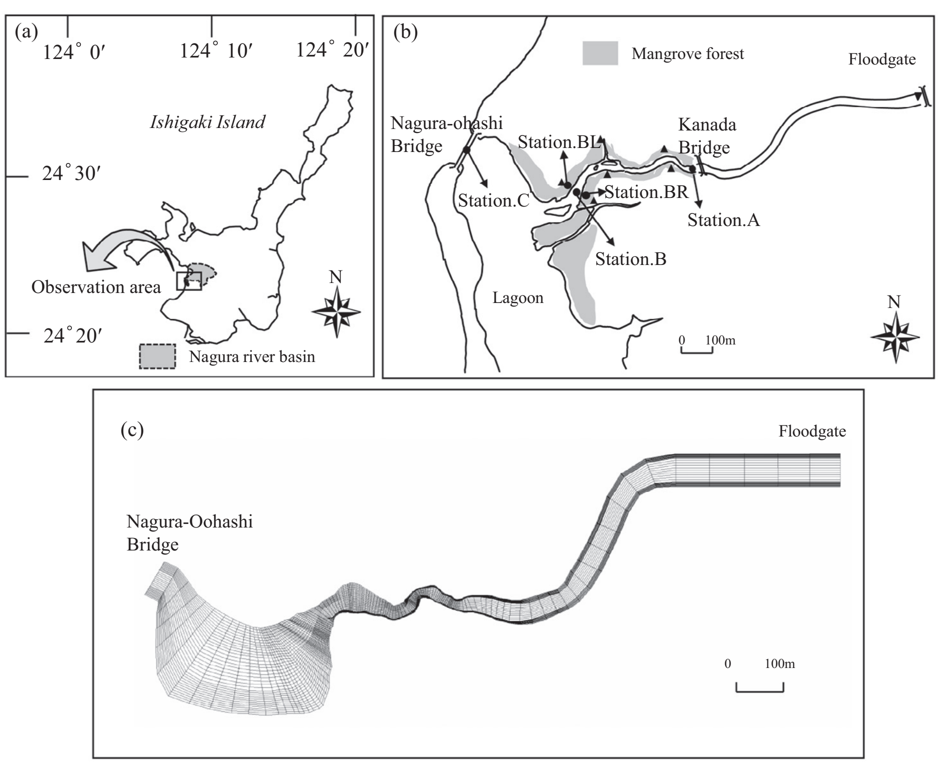

Fig. 1. Map of (a) Ishigaki Island, (b) observation area and (c) computational grid.