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Review article

Sediment discharge and export of fluvial carbon and nutrients into the Arafura and Timor Seas: A regional synthesis

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ABSTRACT

The Arafura and Timor Seas (ATS) are a crucial link between the Indian and Pacific Oceans and play a vital role in global ocean circulation and climate. Some high-standing islands in the ATS are globally significant sources of sediment. Here we derive a synthesis of river catchments and their role as sources of water, sediment, carbon, and nutrients to estimate the pathways, magnitude, and fate of exported riverine materials. The edge of the Australian continental shelf and slope receives riverine sediment from Asia as isotopes suggest a mixing of sediment sources, with some overlap between the Australian and non-Australian material, including evidence of significant input of volcanic material from Indonesia. The catchments bordering both the Arafura and Timor Seas account for ≈12% of sediment and ≈35% of water discharged from tropical Asia. Northern Australia discharges a volume of freshwater comparable to southwest New Guinea, but 50–65% of total sediment (754 Mt), DIC (61.1 Mt), POC (7.9 Mt), DOC (3.5 Mt), TN (2.88 Mt), and TP (254,264 t) delivered annually to the ATS come from New Guinea. The island of Timor discharges much smaller amounts of water (170 $km^3\ yr^{-1}$) and sediment (133 $Mt\ yr^{-1}$), but area-specific rates of DIC (1150 $t\ km^{-2}\ yr^{-1}$), POC (238 $t\ km^{-2}\ yr^{-1}$), DOC (94 $t\ km^{-2}\ yr^{-1}$), TN (61 $t\ km^{-2}\ yr^{-1}$) and TP (4.4 $t\ km^{-2}\ yr^{-1}$) are higher, reflecting very high rates of deforestation and land degradation. Compared to other tropical rivers, carbon export into the ATS is dominated by DIC. The ATS catchments are being increasingly affected by human activities, and material discharge to the continental margins will likely increase, impacting shelf communities and highly diverse reef, mangrove, and seagrass habitats.

1. Introduction

The transport of land-derived sediments and associated nutrients, carbon, and pollutants from river catchments to adjacent seas has significant impact on a wide variety of oceanographic, biogeochemical, and ecological processes in coastal, continental shelf, and deep-sea environments. For instance, in tropical seas, excess sediments can bury mangroves, seagrass meadows, and coral reefs and can carry nutrients, pathogens, and pollutants into open water with negative impacts on organisms important for human livelihoods (Alongi, 2004). Fine sediment can also reach deep basins where their impact is likely to be small but significant. If sediments carry nutrients into upwelling zones they can further enhance primary productivity. Pollutants associated with these sediments, such as metals and PAHs, can seriously impact coastal and open-water biota.

A critical assessment of the sources, fluxes, and fate of land-based materials reaching the Arafura and Timor Seas (ATS) is necessary as these seas are important in linking the Indian and Pacific Oceans and in playing a role in global ocean circulation (De Deckker, 1997; De Deckker et al., 2002). The world's climate is also greatly influenced by the El Nino-Southern Oscillation (ENSO) phenomenon and the Indian Pacific Warm Pool (De Deckker et al., 2002; Cravatte et al., 2009) that exist in these seas. It is not known how or if water, sediment, carbon, and nutrient transfers in the ATS are influenced by ENSO or whether or not these inputs possibly feedback to control the climate system. The lack of a regional perspective is unfortunate as the marine ecosystems of the ATS are economically and ecologically important for the four nations (Australia, Indonesia, Timor-Leste, and Papua New Guinea) bordering the Arafura and Timor Seas. The ATS region is part of the Coral Triangle, which houses the world's highest marine biodiversity (Foale et al., 2012), yet also contains some of the world's most highly threatened coastal and marine ecosystems (Burke et al., 2011). Further, without a comprehensive picture of the Arafura and Timor Seas it is not be possible to assess the extent of human impacts, or to convince governments, NGOs, and local communities of the need for proper management of catchments. Catchment management already occurs in the region, but most plans are

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local and not based upon a sound understanding of the oceanography, geology, and ecology of these seas (Wasson, 2007).

In order to partly redress these shortcomings, the physical environment of the ATS is critically assessed in this review paper, with focus then given to river catchments and their role as sources of freshwater, sediments, carbon, and nutrients. By doing so, we derive as comprehensive a picture as possible given data limitations of the pathways and fate of materials from catchments to coasts, in order to frame how these processes influence ecosystem dynamics and human impacts in the region.

2. Regional physiography and geology

The Arafura and Timor Seas consist largely of the shallow Australian continental shelf (<200 m deep), extending across most of the Arafura Sea and a large part of the Timor Sea (Fig. 1). On its northern margin, the shelf downwarps into the Timor Trough which reaches a maximum depth of ~3000 m; water depths are similar along the Banda Arc southeast of Tanimbar and Kai Island groups. North of the Timor Trough lie the outer arc islands of Timor, Tanimbar, Kai, and many other small islands. Further north and northwest are islands of the inner volcanic arc consisting of Flores, Alor, Wetar, and small islands to the east and northeast. Further north and northwest of these islands are several basins, the deepest of which is the Weber Deep (~7000 m), extending to the islands of Sulawesi, Buru, and Seram. The inner volcanic arc also extends west to the islands of Lombok, Bali, and Java.

The topography of land mass reflects the geodynamics of the region. The Australian continent is colliding with the Eurasian Plate in Timor, and being subducted beneath the Eurasian Plate to the west and east of Timor (Keep and Haig, 2010). Collision has produced a complex interleaving in Timor of rocks of Australian and inner volcanic arc origin (Keep and Haig, 2010), with uplift the result of blockage of the subduction channel, break-off of the subduction slab, and isostatic response (Kaneko et al., 2007). Hence there are few earthquakes in Timor. By contrast, uplift further east along the outer arc is subduction-related and earthquakes are common. Along the northern and northeastern margin of the Arafura Sea, uplift of the island of New Guinea (up to 5030 m elevation in Papua Province of Indonesia) is a product of collision of the Australian and Pacific Plates, and the southern margin of the island receives huge volumes of sediment eroded from the rising highlands (Verstappen, 2000). The Pacific Plate is being subducted at the Seram Trough (Fichtner et al., 2010). Australia is subdued, generally much less than 1000 m in height, a consequence of a long history of denudation and subsidence as the continent moves toward the subduction zone (Sandiford, 2007). Elevations of nearly 3000 m occur in Timor because of uplift over ~3 Ma. Subduction-related uplift further east along the Banda Arc is more recent, so elevations of the islands are only a few hundred meters.

The islands of the inner volcanic arc are very different. Java consists mostly of Tertiary sedimentary and volcanic rocks, with a central spine of volcanoes, many of which are active. The highest elevation is on the volcano Gunung Arjuna at 3239 m in east Java. Bali, Lombok, Sumbawa, Flores, and Pantar islands also have active volcanoes with maximum elevations ranging from 1753 to 3726 m. Sumba has no active volcanoes, but an old eroded volcano reaches 1235 m. The islands of Alor, Ata'uro, and Wetar are volcanically inactive, a consequence of blockage of the subduction channel by the collision with Australia (Merritts et al., 1998). Further east along the inner arc, volcanoes form the islands of Teon, Nila, and Serua, and Banda Api near Seram.

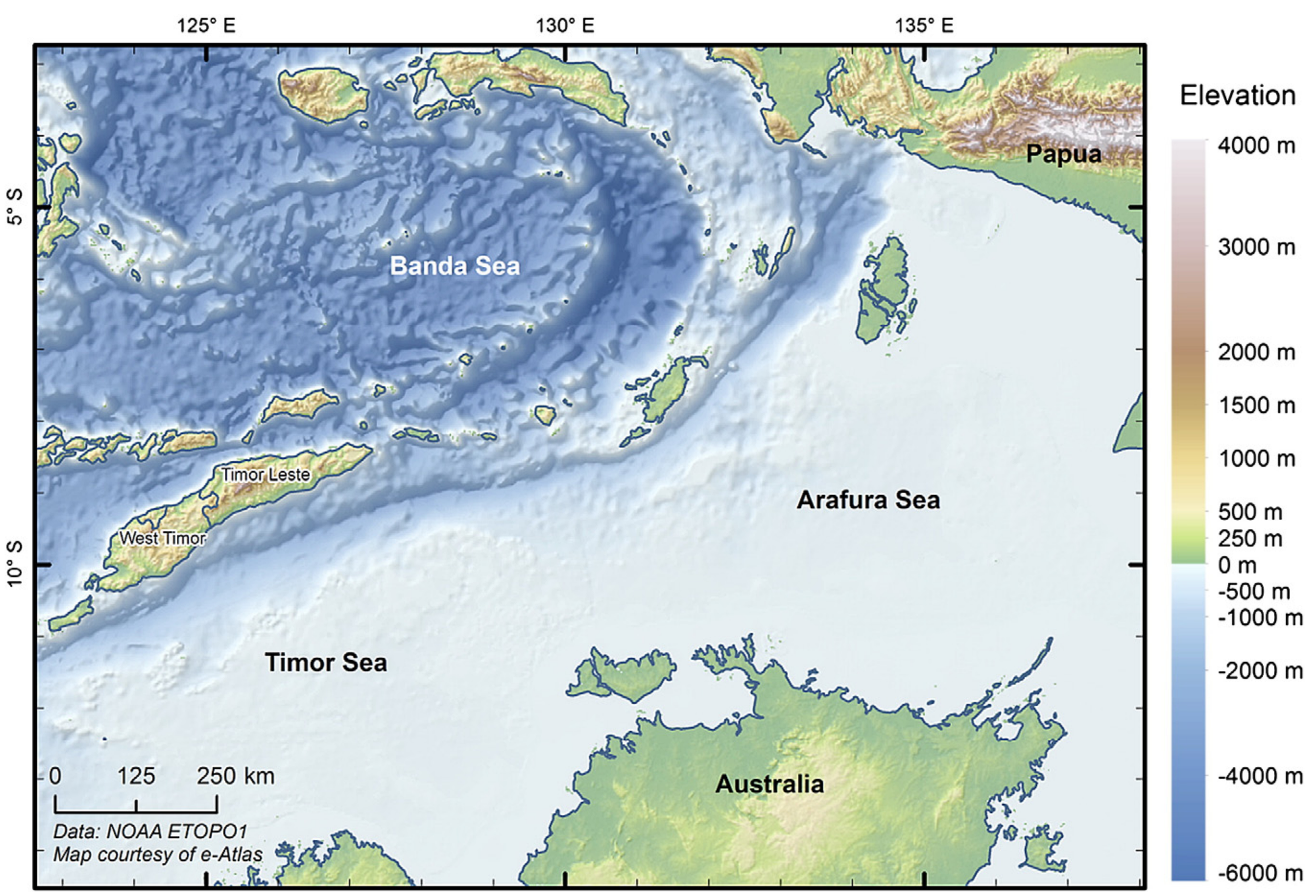

Fig. 1. Map of the entire Arafura and Timor Seas region showing principal land masses, topography, and bathymetry. Data courtesy of NOAA ETOPO1, USA.