Potentially massive greenhouse-gas sources in proposed tropical dams

Construction plans for hydropower dams on tropical rivers, like the Amazon and Lower Mekong rivers, have raised worldwide attention (eg Fearnside 2006; Stone 2011). Particularly, the negative impacts of dams along the Mekong River on the region's fisheries, food security, and riverbank erosion, as well as the associated incidence of vector-borne diseases, have been comprehensively reported (Stone 2011). However, one serious detrimental consequence has so far largely been ignored: massive greenhouse-gas (GHG) emissions potentially associated with the proposed dams.

Hydropower has traditionally been regarded as a source of "green energy"; however, studies have identified the role of dams in promoting GHG emissions (St Louis *et al.* 2000; Barros *et al.* 2011). After reservoir basin inundation, the readily decomposed carbon stocks in now-submerged plants and soils are largely converted to carbon dioxide (CO_2) or methane (CH_4) (St Louis *et al.* 2000; Barros *et al.* 2011). Furthermore, in warm climates like those in the tropics, relatively high temperatures will accelerate organic matter decomposition (St Louis *et al.* 2000). After a large pulse of GHG emissions in the first few years post-inundation, emissions can continue at a lower but still substantial rate (St Louis *et al.* 2000). Although field measurements of GHGs from Southeast Asian reservoirs are unavailable, the latest global estimation has indicated that tropical (25°N–25°S) hydroelectric reservoirs can emit 844.7 milligrams CO_2–C per square meter per day (mg CO_2–C m^{-2} d^{-1}) and 2.2 mg CH_4–C m^{-2} d^{-1}. These values are more than six times and three times, respectively, the typical emission rates for reservoirs at temperate sites (Barros *et al.* 2011). All of the planned hydropower projects on the Lower Mekong River occur between 10°N and 20°N (Figure 1). Considering that the total combined inundated area produced by nine of the proposed Mekong River dams (Pak Beng, Luang Prabang, Xayaburi, Pak Lay, Pak Chom, Ban Koum, Don Sahong, Stung Treng, and Sambor) is estimated to extend over 2120 km^2 (Save the Mekong 2011), these dams (if built) could cumulatively contribute 2.5 teragrams (Tg, where 1 Tg equals 1×10^{12} g) CO_2 equivalents per year. Because this recent emissions estimate is a global average that includes many older reservoirs (Barros *et al.* 2011), the actual impacts of the planned dams on the Mekong River are likely to be much higher, especially in the first few years.

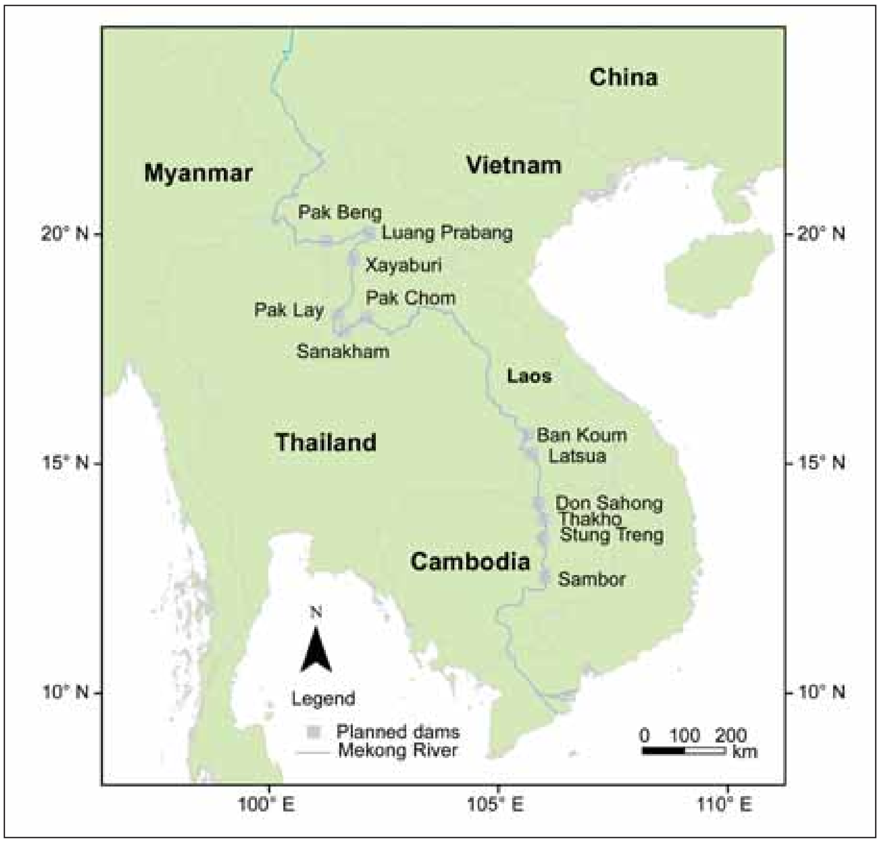

Figure 1. *Site locations of 12 proposed dams on the mainstream of Southeast Asia's Lower Mekong River.*

In this context, it is to be welcomed that construction regarding the proposed Xayaburi Dam along the Mekong in Laos has again been delayed, following the December 2011 meeting of the Mekong River Commission (MRC). Nevertheless, the ultimate fates of the Mekong River dams are still unclear, and impartial, science-based evidence to help guide hydrological planning efforts remains inadequate. The MRC's Strategic Environmental Assessment evaluated the power generation and security, economic development and poverty alleviation, ecosystem integrity and diversity, fisheries and food security, and social systems associated with these planned hydropower dams (ICEM 2010), but GHG emissions did not receive any attention. Further studies, especially those that include accurate field measurements of GHG emissions from the Mekong River system, are needed. Vegetation clearance prior to inundation can reduce the stock of material available for methanogens and therefore decrease subsequent GHG emissions. Although such clearance efforts should be considered as one of the strategies to mitigate potential GHG emissions from dams, many other ecological issues remain – not the least of which concern the predicted effects of global warming, altered flow regimes, and increased organic waste loading within the river system. These impacts, though unknown quantitatively, are almost certain to exacerbate the detrimental impacts of dams and reservoirs on this major Southeast Asian river.

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Lost locations and the (ir)repeatability of ecological studies

Peer-reviewed letter

A basic principle of conducting sound scientific experiments is that they be repeatable. Thus, a published study ideally includes all pertinent details necessary to replicate the experiment. For laboratory-based research, this task is relatively simple, given that – for instance – chemicals, equipment, temperature, and experimental time/duration can be easily controlled. In the field, however, where conditions are impossible to control and may be constantly changing, conducting repeatable experiments is more challenging. These problems are magnified and become more complex over larger areas, characterized by increasing numbers of uncontrollable variables (Kraufvelin 1999). The repeatability of field studies is therefore limited, to the detriment of the science of ecology because this is essential for establishing general ecological principles (Cassey and Blackburn 2006). Although the contingent nature of ecology complicates establishing universal laws, many generally observable patterns and rules can be established from research. The more repeatable our studies, the more robust these rules will become (Lawton 1999).

Perhaps the difficulties in attaining accurate locational descriptions of study sites – despite the presence of new, widely available geospatial technologies – have contributed to hindering improvements in repeatability. A recent study of marine research publications found that 13% of analyzed articles contained no specific geographic information; for those that did include geographic information, a 5% error in reported spatial location was detected (Fisher *et al.* 2010).

To determine the repeatability of study locations, we reviewed site descriptions from 1 year of published articles in both *Ecology* and *Oecologia*, counting the total number of articles in which location was relevant (eg field experiments or observations). Of these 488 articles, 27.3% omitted maps and geographic coordinates, including only vague descriptions of study areas (eg providing only the name of a park or county); 13.7% included maps; and 57.6% contained coordinates. Of the subset of articles containing spatial coordinates, over two-thirds were accurate to the minute, which can cover an area of up to ~3.4 km^2, depending on distance from the equator; 4.6% were accurate only to the degree, which could include an area of hundreds of square kilometers; and 7.8% were accurate to the fraction of a second, which narrows the area to a few tens of square meters.

By comparing reported spatial coordinates with the description of a location using Google Earth (www.google.com/earth), we determined the prevalence of spatial errors. If a set of published coordinates were claimed to be associated within the boundaries of a certain location (eg country, island, lake) but in reality were not, this was counted as "incorrect". This only includes coordinates that were obviously incorrect: for example, coordinates purported to be on an island that were in fact in the adjacent ocean or coordinates in a different country than described. If coordinates could be located somewhere within the described site (eg inside the boundaries of a park), this was not classified as incorrect, regardless of how precise the coordinates were. Of geographic coordinates provided in the published articles, we found that nearly 16% were incorrect.

Consequently, we argue that geographic coordinates may not be the best method for describing study sites. Although adequate for describing a particular point (eg a woodlot or a small pond), coordinates are not particularly useful in studies conducted over larger areas (ie coordinates alone do not provide enough information to repeat the study). Instead, we suggest using KML (Keyhole Markup Language) files, such as those used by Google Earth, to store information and images; KML files can be included in electronic supplements or appendices, available in most journals. In many areas, Google Earth images can "zoom in" close enough to allow the user to even see individual trees and thus better understand the landscape, which also facilitates analysis on multiple scales simultaneously.

Given these possibilities, we rec-

Panel 1. Examples of reporting accurate locations for ecological studies using Google Earth

Point samples

Through the use of point counts of bird abundance and other variables, this study compared the potential of birds to control pests in forests. In all, there were 40 points. Although it is possible to list the exact geographic coordinates of each point in a methods section of a research article, this would not be a user-friendly way to find the locations. A KML file, however, easily allows the reader to view where point samples were taken (in this example, the associated file can be accessed at www.obki.hu/munkatarsak/BaldiA/Point_sample.kmz).

Line (transect) samples

In this MSc thesis work, the influence of different linear landscape elements on pollinator abundance was studied. There were three replications of each transect, resulting in 12 transects altogether. In a typical paper, a site description might be written as: "Twelve transects were sited in a typical farmland west from Kakucs in central Hungary, Europe". Using a KML file as an electronic supplement, however, researchers can give the accurate location for each transect (in this example, the associated file can be accessed at www.obki.hu/munkatarsak/BaldiA/Line_transect.kmz).

Polygon (area) samples

This is a part of a study that aimed to compare breeding and wintering birds in agricultural areas in central Hungary. These grasslands and shrublands (abandoned grasslands) were visited to record bird presence. Text alone would be insufficient for accurately describing location. Geographic coordinates can provide details, such as the center of each field, which would allow accurate relocation. A KML file, however, gives the actual delineations of the fields (in this example, the associated file can be accessed at www.obki.hu/munkatarsak/BaldiA/Polygon_sample.kmz).

ommend that locations be reported as accurately as possible through the use of field measurements by GPS devices and/or images from Google Earth or other online "digital globes". These locations should be reported in a form that allows the reader to locate it exactly (for examples of applications of KML files for point, line, and polygon sites in field studies, refer to Panel 1). However, as technology improves, today's formats and software will eventually become obsolete. Therefore, we suggest that the latitude and longitude coordinates of a location should also be provided.

Satellite imagery and aerial photographs, such as those in Google Earth, show relevant details about locations that coordinates and maps cannot. Combined with field observations, such images (1) provide accurate, detailed geographic and vegetation-related information; (2) reduce the costs of performing field-based studies (Asner *et al.* 2011); and (3) facilitate long-term monitoring and allow researchers to repeat experiments to account for landscape-scale changes (Defries and Townshend 1999; Sutter *et al.* 2011). We believe that accurate location information, provided by KML files in particular, improves the repeatability and quality of ecological research.

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