BIOMONDO Pilot 3

Monitoring river connectivity and impact on biodiversity

Obstacles such as dams and other human-made waterworks heavily alter and interrupt dispersal routes for many species, including aquatic invertebrates (Grönroos et al. 2013), fish (Barbarossa et al. 2020; Duarte et al. 2021) and plants (Merritt & Wohl 2006). In addition, river dams and other human-made waterworks change the natural flow regimes and habitats of aquatic and semi-aquatic species in rivers (Poff et al, 2010; Poff & Zimmermann, 2010; Janse et al, 2015) and river floodplains (Kuiper et al., 2014). Other effects of dams on biota occur via water quality deterioration and reduction of sediment transport to coastal wetlands. Consequently, removal of dams is an explicit target in the EU Nature Restoration Plan, which aims that at least 25,000 km of free-flowing rivers should be restored. River dams, however, are also important in less developed countries, and are welcomed as a source of renewable energy (e.g. hydropower) when combatting climate change. These benefits come at a cost for biodiversity as, for example, discussed in Winnemiller (2016) who found that "Long-term ripple effects on ecosystem services and biodiversity are rarely weighed appropriately during dam planning in the tropics". Dam-building thus provides a real challenge when developing environmental and developmental policies and requires careful consideration of pros and cons.

The dispersal of species within and between freshwater ecosystems is limited for two reasons: 1) because there is little exchange of organisms between river basins (Leuven et al. 2009) and 2) because dispersal is constrained by the dendritic (tree-like) structure and directional flow of river networks (Hänfling & Weetman 2006; Carrara et al. 2012; Wubs et al. 2016). The limited ability of freshwater species to reach sites via dispersal as a consequence of these limitations (Shurin & Smith 2006) reduces biodiversity (Shurin et al. 2000; Irz et al. 2004), and the effects of human-induced habitat fragmentation can be expected to be particularly severe for freshwater ecosystems. In particular, because fragmentation in dendritic river networks creates habitat patches that are smaller and more varied in size when compared to terrestrial landscapes (Fagan 2002; Fuller et al. 2015; Yi et al. 2010). The multiple, simultaneous effects of river dams, e.g. on species dispersal routes, water flows and water extent, and water quality, including differences in these effects between different types of dams, however, are not well understood. Satellite Earth observation is a suitable tool to improve the inconsistent global information basis for assessments of these multiple effects and associated restoration goals.

In this pilot, we focus on the impact of river dams on freshwater ecosystems at river catchment scale and use this as the basis for formulating the requirements for upscaling to the global scale. **More specifically, the objective of this BIOMONDO pilot is to explore the possibilities for combining EO data and biodiversity modelling for monitoring and assessing the impact of dam construction and removal on biodiversity, including the effects on:**

1) **Habitat fragmentation and dispersal routes**
2) **Changes in habitat extent**
3) **water quality (e.g. through influences on sedimentation and turbidity).**

These effects correspond to three pilot objectives and contribute to the science question "How will the diversity of life and ecosystem services in freshwater systems change with increasing change in habitat?". This, in turn, will pave the way for a further assessment of the impact of river dams on wetlands (e.g. the extent of wetlands before and behind a river dams may change considerably), and the assessment of other human-induced changes (e.g. canalization) on river biodiversity (as part of the Roadmap).

We will assess the impact of past, current, and (planned) future dams, as well as the potential for dam removal to increase connectivity, using a species-specific modelling approach. More specifically, we will model the impact of river dams on the geographic range connectivity of ~10 000 fish species living partially or exclusively in rapidly flowing freshwater (e.g. rivers) for entire drainage systems, i.e. the patterns formed by the streams, rivers, and lakes in a particular drainage basin. The impact of dams may differ between fish that complete their lifecycle in freshwater and fish species that migrate between freshwater and marine environments. Specific connectivity measures will, therefore, be adopted for driamous and nondriamous fish species, following a procedure co-developed by members of BIOMONDO and described in Barbarossa et al. (2020). This procedure results in an assessment of the degree of geographic range fragmentation, expressed as a connectivity index (range 0-1) where 1 represents a range that is fully connected and 0.5 results from a dam dividing a range into two equally sized fragments.

Several datasets on *the locations of dams* are available, including approaches where satellite observations are used. These datasets vary in terms of quality, coverage and definitions of dams, and also the attributes provided vary among them, which pose challenges on their use for global assessments and impact studies on biodiversity. At catchment level, reasonably consistent level of dam datasets, however, exist, at least for major rivers. The situation is comparable for the other parameters listed above: *land cover / land use data sets exist to monitor changes in habitat extent* but with varying quality and legends when it comes to spatial high resolution. ESA CCI provides an excellent time series at 300m with 42 internationally agreed classes. Recently ESA has released the 10m Worldcover classification with 10 classes. The latter would have the required spatial resolution but is lacking the temporal dimension. If we find that the existing data are not suitable for our purpose, we will study options to improve existing methods, or develop a new one, in particular by facilitating latest improvements by AI/ML. *There are no operational EO data services for river water quality and turbidity*, so we need to process this on our own.

The results of this pilot may contribute to the further improvement of the GLOBIO fish habitat module and may help quantify impacts of dam-induced changes in water flows on biodiversity intactness using the Mean Species Abundance (MSA) indicator in GLOBIO-Aquatic.

Pilot sites

We have chosen the Greater Mekong region as the as the primary site for this pilot. This region holds irreplaceable riches—ranging from rare wildlife in spectacular natural landscapes to communities with distinct cultural heritages. The vast region spans six countries: China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam. Its 809 000km^2—the combined size of Germany and Sweden—contain some of the most biologically diverse habitats in the world. This is the 'rice bowl' of Asia and at its heart lays the Mekong River. Winding almost 3,000 miles from the Tibetan plateau down to the South China Sea, the Mekong River boasts the world's largest inland fishery. It accounts for up to 25 percent of the global freshwater catch and provides livelihoods for at least 60 million people. It is second only to the Amazon River in terms of fish biodiversity. At least 1,100 freshwater species swim the waters of this mighty river including the last remaining populations of the Irrawaddy dolphin, giant freshwater stingray which can weigh up to 1,300 pounds, and the Mekong giant catfish.

Unprecedented social and economic development in the Greater Mekong makes conservation work here especially urgent and significant. The most pressing threats are hydropower development, climate change, illegal wildlife trade and habitat loss. An example of the impact of the dams in the Mekong River system on the environment and thus ecosystem services is given by Eyler (2020), in his essay "Science shows the Chinese Dams are devasting the Mekong". This construction of the Nuozhadu dam in 2012 had a dramatic effect on the water level and the normally occurring flooding events along the river (see Figure 1).

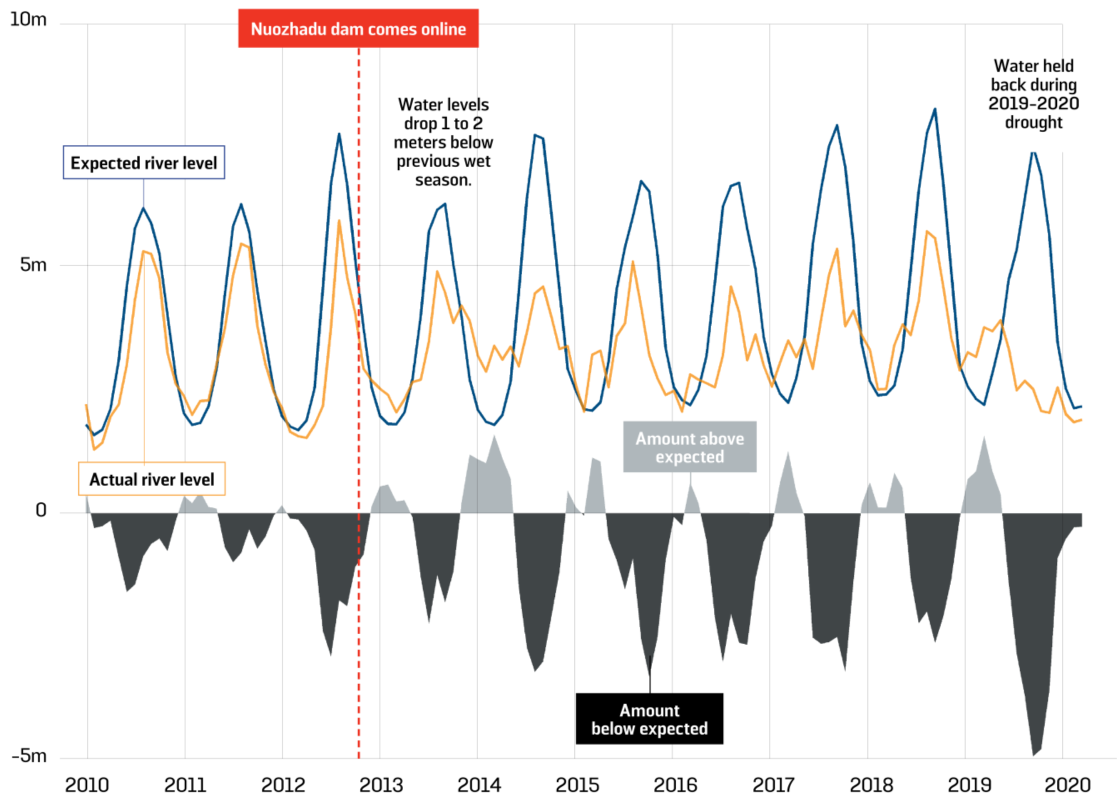

Figure 1 Impact of the Nuozhadu Dam on the Mekong River; river heights in meters. From Eyler 2020. Data source: Eyes on Earth, Mekong River Commission. The river water level is taken from NASA's Eyes on Earth system.

Wikipedia reports for 2016 a total number of 56 dams in use for hydropower energy in the Mekong River basin (i.e. for the Mekong river and its tributaries): Laos 23, China 18, Vietnam 10, Thailand 5. Another 31 dams were under construction. Most of the dams have been built after 1994, and more than 2/3 of them, after 2009. Time series of when these dams were placed are available, allowing us to study changes in the connectivity of the Greater Mekong area and to assess whether critical percolation points have already been passed (see Figure 2). More specifically, Landsat 5 data allows an assessment of the area in almost unregulated conditions. With ENVISAT MERIS, ASAR and AATSR, and Landsat 5 and 7, the situation before the big increase of dam constructions happened is captured.

The situation after 2016 is well measured by Sentinel 2, Sentinel 3 and Landsat 8. This suite of EO sensors allows mapping of land cover / land use, water extent and water quality. With the MWR on ENVISAT and Sentinel 3 also the water level can be measured (with the known limitations for rivers). The Land Cover CCI long term time series back to 1992 allows excellent mapping of the river basin even if at a spatial resolution of only 300m. Ready-to-use thematic data (Level 2, Level 3) are available from ESA CCI (Medium Resolution Land Cover, Lakes) and Copernicus (C3S Land Cover, CLMS Global – Hydrosphere).

The Mekong Dam Monitor[1] is an online platform which uses remote sensing, satellite imagery, and GIS analysis to provide near-real time reporting and data downloads across numerous previously unreported indicators in the Mekong Basin. Among others, it provides weekly updates of high-resolution satellite images (10-meter Sentinel imagery) of all 13 completed dams and reservoirs on the Mekong mainstream in addition to 13 tributary dams with power generation capacities greater than 200 MW, and also weekly reservoir level readings (meters above sea level) and operation curves of those dams. The platform is freely available for public use and all research inputs are public-access resources.

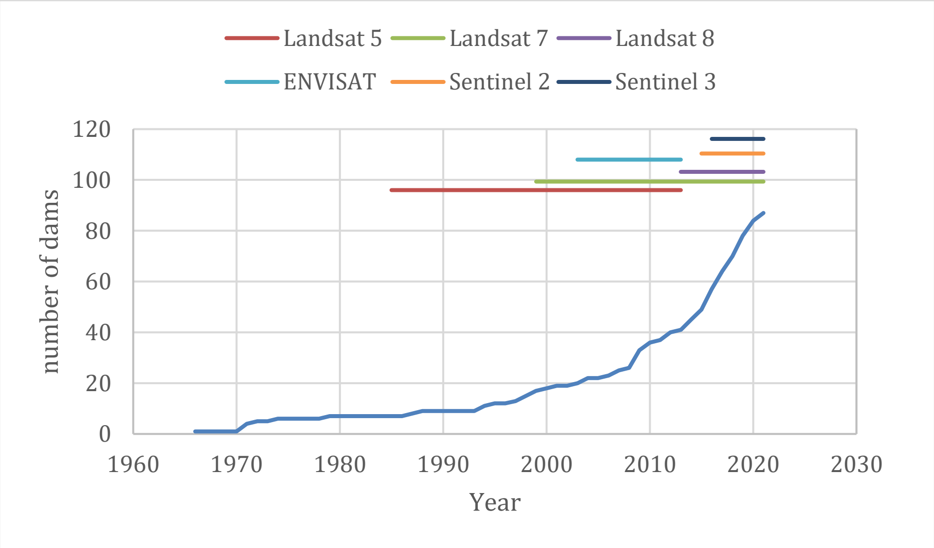

Figure 2 Timeseries of number of dams (blue line) in the Mekong Basins from 1960-today and the availability of EO data for different sensors within this time period.

The Mekong basin will furthermore be one of the focus regions of the Horizon Europe project SOS-Water. This four-year project was selected in the HORIZON-CL6-2021-CLIMATE-01 call, and will start in the second half of 2022 with EAWAG as a partner and the Mekong River Commission's Dr. So Nam as a stakeholder. It will investigate safe operating spaces for water resource management with regards to all socio-economic and ecological values, including biodiversity.

[1] https://www.stimson.org/project/mekong-dam-monitor/

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