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Marcus W. Beck, Andrea H. Claassen, Peter J. Hundt

Conservation Biology Graduate Program, University of Minnesota, 200 Hodson Hall, 1980 Folwell Ave, St. Paul, MN, 55108, USA

Conservation Biology Graduate Program, University of Minnesota, 200 Hodson Hall, 1980 Folwell Ave, St. Paul, MN, 55108, USA

Conservation Biology Graduate Program, University of Minnesota, 115 Ecology, 1987 Upper Buford Circle, St. Paul, MN, 55108, USA

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Environmental and livelihood impacts of dams: common lessons across development gradients that challenge sustainability

MARCUS W. BECK, Conservation Biology Graduate Program, University of Minnesota, 200 Hodson Hall, 1980 Folwell Ave, St. Paul, MN, 55108, USA. Email: beckx266@umn.edu (author for correspondence)

ANDREA H. CLAASSEN, Conservation Biology Graduate Program, University of Minnesota, 200 Hodson Hall, 1980 Folwell Ave St. Paul, MN 55108, USA. Email: claas004@umn.edu

PETER J. HUNDT, Conservation Biology Graduate Program, University of Minnesota, 115 Ecology, 1987 Upper Buford Circle St. Paul, MN 55108, USA. Email: hundt002@umn.edu

ABSTRACT
The economic benefits of dams have been assumed to outweigh the costs, thus providing rationale for construction of dams around the world. However, the development of these structures can be accompanied by negative biophysical, socio-economic, and geopolitical impacts; often through the loss of ecosystem services provided by fully functioning aquatic systems. Moreover, impacts of dams can be involuntarily imposed on marginalized peoples whose livelihoods are dependent on riverine resources. In this review, we examine the impacts of dam projects in regions of the world that are at different stages of development, using the USA, China, and Southeast Asia to represent a development gradient from developed to developing, respectively. Case studies for each region illustrate the environmental and livelihood impacts of dams in each region, while also providing a basis to better understand how environmental degradation is directly related to economic growth. We conclude that a distinct temporal component related to development mediates the relationship between policies and governance mechanisms and the mitigation of environmental and social costs of dams. The role of affected individuals to influence the political will behind dam projects and the importance of environmental advocacy is emphasized as a fundamental approach towards more sustainable development.

Keywords: Dam; environment; livelihood; USA; China; Southeast Asia

1 Introduction

Rivers have played a major role in shaping the earth’s physical and ecological landscapes through their unique hydrologic characteristics, as well as shaping cultural landscapes by providing food, water, and other ecosystem services. With the rise of ancient civilizations came a rise in building dams and diversions for water storage, irrigation, transportation, and flood control. As early as 6500 BC, the Sumerians constructed dams across the Tigris and Euphrates rivers to provide flood control and irrigation for crops (McCully 2001). By the first millennium BC, stone and earthen dams were erected on nearly every continent, enabling the acquisition of water and food to sustain population growth. Dam technology advanced slowly until the Industrial Revolution when larger dams were built in less time and from man-made materials (DiFrancesco and Woodruff 2007). Today, more than 45,000 large dams (greater than 15 m in height) exist worldwide (DiFrancesco and Woodruff 2007), that provide water supply, flood control, waterpower for mills, hydroelectric power, improved navigation, recreation, and waste disposal (Graf 2002).

The rapid increase in dam projects during the early and middle twentieth century was driven by socio-economic and political pressure to increase the quality and quantity of water for production while simultaneously minimizing its destructive potential (i.e. water security). Advances in structural engineering, such as the use of pre-stressed concrete (Arthur 1977), also contributed to the proliferation of dams. Recently, dam construction in developed countries has decreased as a majority of economically viable projects have already been pursued. Moreover, changes in ideology and a growing awareness of the environmental and social impacts of dams have become important factors that influence valuations of dam projects in developed...
countries (Born et al. 1998, Johnson and Graber 2002). Dams that no longer function for their intended purposes or that pose safety hazards have been decommissioned and removed (Kato-podis and Aadland 2006). However, the political-ecology dimension of developing countries and the multiple utilitarian benefits provided by dams continue to favour the proliferation of these structures in regions where the resources offered by free-flowing rivers provide incentive for industrial and infrastructure development (Goodland 1997). The potential negative impacts of dams on the environment and natural resource-based livelihoods of local peoples are often considered by decision-makers to be acceptable costs relative to the economic benefits these structures can provide.

1.1 Negative impacts of dams

The impacts of dams on the biological, geophysical, and chemical processes of rivers have been extensively documented (Goldsmith and Hildyard 1984, Petts 1984, Graf 1999, WCD 2000). Although specific environmental impacts of dams are influenced by local conditions, as well as the size and type of dam constructed, similar environmental impacts of dams have been documented in various regions of the world, and are generally not unique to a specific location or ecosystem.

Negative environmental impacts of dams can occur upstream, downstream, and in reservoirs. In addition to habitat degradation or destruction, dams induce significant barrier effects by blocking the downstream flow of sediment and nutrients and preventing the migration of fish and other aquatic organisms (Lessard and Hayes 2003, Meixler et al. 2009). Additionally, altered flow rates may negatively impact aquatic organisms that depend on critical thresholds of water level, velocity, or timing for life history stages (Bunn and Arthington 2002, Dugan et al. 2010). Dams may also negatively impact aquatic organisms by altering water temperature and dissolved oxygen both within reservoirs and outflows (Lessard and Hayes 2003). Reservoirs may also contribute to atmospheric greenhouse gases (e.g., carbon dioxide and methane) through the decomposition of flooded biomass and soils (St. Louis et al. 2000, Mäkinen and Khan 2010).

The creation of a reservoir from damming a river has multiple social and economic impacts on individuals living near the dam project. Resettlement and loss of land from reservoir inundation is the most prominent impact from dam construction. Environmental impacts of dams and consequent reduction in access or availability of fish and other riverine resources may negatively impact human livelihoods as well. Reservoir fisheries may be poor substitutes for river fisheries as a result of lower productivity and the need for periodic restocking of introduced fish populations that are not self-sustaining (Marmula 2001, Baran et al. 2007). In many parts of the world, fish and other riverine resources are critical to sustaining human livelihoods by providing food and financial security (Shoemaker et al. 2001, DiFrancesco and Woodruff 2007). Indigenous groups pursuing subsistence lifestyles are often the most heavily impacted by loss of natural resources from dam construction (McCully 2001). Reservoirs also increase health risks for individuals that maintain physical connections with aquatic environments. Reservoirs provide breeding habitat for vectors of water-borne diseases, such as malaria and schistosomiasis, which otherwise are found in substantially lower abundances in undammed rivers (Goldsmith and Hildyard 1984).

Additionally, flood control is a major incentive for building dams. However, a decreased occurrence of natural flooding reduces downstream sediment deposition important for restoring the fertility of riparian areas (Shoemaker et al. 2001, Lebel et al. 2005). Flood control may also give a false sense of security potentially causing more loss of life and property during unusually large flooding events than if no flood control structures were in place (Lebel et al. 2005). Many cases exist where dam failure during construction or aging was disastrous for local communities (Baird et al. 2002, Graham 2009). Indeed, safety concerns (followed by environmental concerns) are the leading reasons for removal of dams in Wisconsin, USA (Born et al. 1998).

Finally, dams have impacted the cultural, aesthetic, and recreational values of natural rivers. Although dams and reservoirs may also provide some of these benefits (Doyle et al. 2000, Anderson et al. 2008), river-based recreational activities and river-front property associated with dam removal may provide more long-term cultural, aesthetic, and recreational benefits (Sarakinos and Johnson 2002, Provencher et al. 2008). Additionally, dam projects that displace indigenous populations can greatly erode social cohesion leading to long-term losses in culture (Goldsmith and Hildyard 1984, Garrett 2010).

1.2 Sustainability of dams

The global increase in construction of dams during the twentieth century and the associated negative impacts has brought attention to the need for project managers and financiers to adopt more sustainable practices in construction, operation, and eventual removal of dams. The World Commission on Dams (WCD) was established in 1998 to promote more sustainable approaches to dam development. The WCD report was released in 2000 as both an assessment of effectiveness of large dams and a proposed international framework for planning, appraisal, construction, operation, monitoring, and decommissioning of dams (WCD 2000, Moore et al. 2010). The framework of the WCD is complex and promotes the use of three global norms, five core values, five key decision points, seven strategic priorities, 33 associated policy principles, and 26 guidelines in implementation and advocacy of dam-related activities. For example, core values such as participatory decision-making and equity have relevance to costs distribution of dam development. Although the WCD report documented the inadequacies of many dam projects, the proposed framework was not universally accepted. Many international governments and financiers considered the guidelines to be overly stringent, such that
Implementation would discourage further infrastructure development (Fujikura and Nakayama 2009, Moore et al. 2010). A decade after the release of the WCD report, opinions on the effectiveness of the WCD guidelines for improving sustainability of dam projects remains contentious (see Moore et al. 2010).

Other international initiatives have gained recognition for promoting more sustainable development paradigms in dam projects. The most notable precursor to the WCD framework is the Dublin Principles, established in 1992 at the International Conference on Water and the Environment (ICWE 1992). The Dublin Principles consist of four recommendations for more sustainable use of water resources, which recognize participatory approaches to water use and also establish the basis for integrated approaches to water resource management advocated by international organizations such as the Global Water Partnership (GWP 2010). However, the Dublin Principles and integrated water resource management have been criticized for difficulties in economic valuation of water resources (Savenije and van der Zaag 2002) and practical applications (Garcia 2008). A more contemporary approach to sustainable use of rivers is the 2007 Brisbane Declaration established at the 10th International River Symposium and International Environmental Flows Conference (Brisbane Declaration 2007). The Brisbane Declaration identified a list of key findings and global action agendas relevant to the preservation and restoration of environmental flow regimes. Fundamental to the Brisbane Declaration was the need to actively engage all stakeholders in decision-making by considering the full range of human needs and values as a basis for more effective environmental flow management. The key findings and global action agendas of the Brisbane Declaration have promoted research efforts in support of environmental flow assessment and implementation (Arthington et al. 2010), although the application of these principles to achieve more sustainable development of dams has yet to be shown.

More broadly applicable approaches not specific to dams have also provided arguments for sustainable development. Ecosystem services are broadly defined as the benefits humans receive from ecosystems, including provisional, regulating, cultural, and supporting services (MEA 2003). Quantifying ecosystem services is an assertion that normally functioning environments provide anthropocentric services with intrinsic worth. As such, ecosystem services provide conceptual linkages between environmental condition and human well-being, having tremendous potential for conservation and restoration (Brauman et al. 2007). The negative environmental and societal impacts of dam projects have undoubtedly degraded or eliminated many services provided by ecosystems. The degradation of ecosystem services caused by dams has been quantified in several studies, but multiple institutional and economic barriers may prevent the implementation of safeguards for protecting the environment (Ebisemiju 1993, Brismar 2002). Additionally, the quantification of services that have no well-established markets, such as cultural or spiritual values provided by ecosystems, has proved difficult (Hanley et al. 1998).

1.3 Objective and approach

Current global trends suggest multiple challenges to sustainable development still persist despite guidelines promoted by past efforts such as the WCD, Dublin Principles, Brisbane Declaration, and valuation of ecosystem services. Holistic assessments of costs of dam projects are rarely conducted, particularly because many costs are not easily quantified or political and cultural climates may provide disincentives for more sustainable approaches. Although costs can be distributed across many segments of society, rural and under-represented individuals often share a disproportionate amount, particularly through loss of resource-based livelihoods (Goldsmith and Hildyard 1984). The objective of this review is to facilitate a broader discussion of challenges for implementing more sustainable practices in the development, operation, or removal of dams by emphasizing commonalities and trends in countries at different stages of economic development. We suggest current practices do not indicate sustainability, particularly through impacts on the environment and livelihoods of marginalized members of society. The role of affected individuals in political processes has profound implications for improving infrastructure development paradigms and is emphasized as a preliminary approach towards sustainable development. More importantly, we suggest common themes preventing sustainable development (defined in WCED 1987) exist regardless of a country’s economic status, although the fundamental drivers of environmental degradation vary with development.

The consequences of unsustainable dam construction have been well documented, providing an abundance of examples for review. As such, we focus on three different regions, each having a unique history, culture, and development trajectory, to establish a context of examination for global trends related to dam projects. First, we discuss the USA, a developed country with a detailed history in large infrastructure projects. Second, we discuss the dam industry in China, a moderately developed country with dramatic economic growth and increasing demand for resources. Third, we discuss Southeast (SE) Asia, a developing region that exemplifies the influence of a global economy on the environment and society. We also discuss key examples of dam projects in each region that illustrate unique issues and commonalities of dam projects in a sustainable development context. Emphasis is given to environmental impacts of dam projects and how loss of resources translates to loss of livelihoods of affected peoples.

2 Regional studies of dam development: USA, China, and SE Asia

2.1 USA: a developed nation shifting towards dam removal

2.1.1 Brief history of dam construction in the USA and impacts on Native Americans

The building of infrastructures, such as dams, has been a primary focus of economic development during the brief history of the
USA. The construction of single-purpose dams began in the early 1820s during the Industrial Revolution (Billington et al. 2005). In the early 1930s, multipurpose dams were constructed, such as the Hoover Dam on the Colorado River (Billington et al. 2005). Construction of dams in the USA peaked between 1955 and 1975 (DiFrancesco and Woodruff 2007). Currently, there are almost 2300 hydropower dams in the USA (Cech 2003), in addition to several million total dams, with reservoirs that cover approximately three percent of the country’s land surface (DiFrancesco and Woodruff 2007). While most of these dams are small (less than 1 m in height), there are estimated to be more than 75,000 dams over 2 m high (Graf 2003), each storing at least 1.2 km$^3$ of water (Graf 2006). Almost all rivers in the conterminous USA are dammed (DiFrancesco and Woodruff 2007) and nearly one million kilometres of waterways have been transformed into reservoirs with a total storage capacity almost equal to the country’s total annual runoff (Graf 2002).

The dams and reservoirs of the USA have had profound impacts on the geomorphology and hydrology of the country’s rivers and streams (Graf 1999), with associated negative impacts on fish (Wunderlich et al. 1994, Lydeard and Mayden 1995, Magnuson et al. 1996, Marmula 2001, Close et al. 2002, Cumming 2004) and those dependent on fish-based resources (Magnuson et al. 1996, Ulrich 1999). Fish have provided a primary source of protein for Native Americans of the Pacific Northwest for over 10,000 years (Sutlles 1990, Butler and O’Connor 2004, DiFrancesco and Woodruff 2007) and also have importance for traditional rituals and medicines (Swezey and Heizer 1977, Close et al. 2002). Anadromous salmonids are particularly impacted by dams as these structures impede movement to spawning grounds, degrade spawning habitat, inhibit migration of juvenile fish to the ocean, change water chemistry and temperatures, and change quantity and timing of stream flows (Magnuson et al. 1996). Consequently, dams have affected Native Americans of the Pacific Northwest by contributing to declines in catch, eroding traditional culture, limiting access to or flooding traditional fishing areas, and causing shifts in diet (Magnuson et al. 1996, Ulrich 1999, Close et al. 2002, DiFrancesco and Woodruff 2007). Many indigenous people have migrated out of the region, whereas those remaining have used costly litigation measures to regain or protect rights to harvest protected fish (DiFrancesco and Woodruff 2007). Many tribes have established livelihoods by operating large fish hatcheries used to stock salmon runs (DiFrancesco and Woodruff 2007), although costs of stocking programmes are considerably high (Michael 1999) and long-term prospects for restoration are bleak in the absence of dam removal (Lackey 2003).

2.1.2 Slow shift in policy toward dam removal

Most US policies related to dams have focused almost exclusively on construction (Graf 2002). However, the utility of a dam is diminished over time through sedimentation of the reservoir and decreasing structural stability (Pohl 2002), suggesting more attention should be focused on policies that outline eventual removal of these structures. Nearly 25% of all dams in the USA are greater than 50 years old, and by 2020, this number will grow to more than 85% (McClain et al. 2006). While dam safety has always been a concern, the structural instability of an aging dam increases the likelihood of failure and possible loss of human life. Dams have been responsible for over 3000 deaths in the USA (DiFrancesco and Woodruff 2007). Removal has also been increasingly viewed as a financially beneficial option, given the lack of services provided by ageing dams (Graf 2002). Dam removal is a relatively new concept that appears antagonistic with the ideology that drives dam construction in newly developing or developed countries. Dams that were viewed as tools to promote economic growth in the USA no longer serve their intended purposes, whereas the long-term viability of these structures in developing countries are rarely questioned by dam proponents.

A notable concern for dam removals in the USA is a lack of sufficient policies for guiding removal activities. The Federal Water Power Act of 1920 (later to become the Federal Power Act in 1935) streamlined the process for hydropower development and created the regulatory precursor to the Federal Energy Regulatory Commission (FERC) to promote and encourage hydropower development in the USA (Kosnik 2006). Under the Federal Power Act, operation of a non-federal dam in the USA requires a license, which is valid for terms of 50 years or less. Consequently, many dams are currently being considered for removal because of relicensing issues (Becker 2006). Surprisingly, the Federal Power Act was devoid of guidance on appropriate actions for decommissioning, which implicitly assumed that the operation of a dam would remain in the best interest of the public (Doyle et al. 2003). A comprehensive decommissioning policy was issued by FERC in 1994, yet these guidelines have not been extensively used in practice (Doyle et al. 2003). Moreover, dam relicensing in the absence of removal can be problematic. Although FERC relicensing can require new operating conditions to address environmental concerns (e.g. increase in minimum flows), these conditions are established in relation to the current river condition as a referential baseline. This approach fails to account for legacy impacts of a dam and implicitly allows loss of environmental capital over time as a result of historical cumulative impacts of the structure (Masonis and Bodi 1998).

Dams are also being removed in the USA because of shifts in public opinion regarding the utility of these structures in environmental or social contexts. As such, policy changes made primarily during the latter part of the twentieth century have slowly shifted the emphasis of public debate to the negative impacts of dams. The Wild and Scenic Rivers Act of 1968, National Environmental Policy Act of 1969, Clean Water Act of 1972, and Endangered Species Act (ESA) of 1973 have enhanced the protection of riverine habitats and species. The country’s environmental legislation emerged as a direct product of the environmental movement of the 1960s and provides some of the most powerful examples of legislative approaches for
restoring and protecting aquatic resources. For example, the level of protection granted to imperilled species and their critical habitat under the ESA is a powerful statement of the political, and therefore public opinion, towards the environment (e.g. Czech et al. 1998), following substantial economic development.

Box 1: Dam removal on the Elwha River

The Elwha River in the Pacific Northwest flows from the Olympic mountains to the Strait of Juan de Fuca in the Pacific ocean. Construction of the Elwha and Glines Canyon dams in the early twentieth century has negatively impacted anadromous fish populations in the river (Pess et al. 2008). Several species have been listed as threatened or protected under the ESA (Wunderlich et al. 1994). Although little information is available on historic population sizes, an estimated reduction of 75% of spawning habitat caused by the dams has likely contributed to decreases in salmonid stocks (Pess et al. 2008). Growing concerns of declining salmonid populations led the US congress to enact the Elwha River Ecosystem and Fisheries Restoration Act of 1992 to restore the river’s ecosystem and allow for recovery of native anadromous fishes (Duda et al. 2008). The legislation was also prompted by relicensing issues with the Elwha Dam more than a decade prior. Relicensing of the Elwha Dam was contentious for a variety of reasons, such as the need to fulfill federal fish and wildlife mitigation standards, proximity to a national park, dam owners’ business decisions, and the cultural, spiritual, and economic goals of the Elwha Klallam tribe. Eventually, removal of both dams was considered the only option for restoring native salmonid populations in the Elwha (Duda et al. 2008).

Arguably, the Elwha Klallam tribe has been most affected by the reduced salmon populations. Salmon have historically provided the tribe with protein and also have importance in religious ceremonies, although declines in stocks were observed as European settlers inhabited the area. Traditional fishing rights were recognized by European settlers in 1855 with the signing of the Point No-Point Treaty. However, construction of the dams effectively negated this treaty by negatively impacting salmonid populations and fish-based livelihoods of the tribe for the following 90 years. The scheduled removal of both dams in 2014 is anticipated to enable the return of native anadromous fishes to upper reaches of the Elwha River. Researchers have prepared for the removal by collecting data on the condition, value, genetic structure of fish populations (Loomis et al. 1996, Brenkman et al. 2008, Winans et al. 2008), and investigating how to monitor population changes after dam removal (McHenry and Pess 2008). The removal of the dams is expected to increase biomass of all salmonids in the region (Wunderlich et al. 1994), having potential benefits for individuals pursuing resource-based livelihoods. Evidence from other projects suggests recovery of fish populations can occur as soon as a few years after removal (Crane 2009). Downs et al. (2009) present an extreme example where adult salmon were observed travelling upstream three days after dam removal.

2.1.3 Review and analysis

Box 1 describes a case study that exemplifies common trends in dam projects of the USA. Construction of the Elwha and Glines Canyon dams was initiated during a period of economic growth in the USA, whereas the dams are currently planned for removal in part because the services for which they were built are no longer provided. The dams have impacted salmonid species that provide multiple ecosystem services, including economic, cultural, and spiritual benefits. The negative impacts on fisheries have imposed substantial costs on indigenous peoples, although removal of the dams are expected to improve fisheries and subsequently restore many of the traditional benefits that salmon have provided for the Elwha Klallam tribe (Wunderlich et al. 1994, Gowan et al. 2006).

Table 1 illustrates the primary impacts of dam projects in the USA and highlights many of the issues discussed in Box 1. The impacts of the Elwha and Glines Canyon dams are certainly not unique to the Elwha River such that costs and benefits can be generalized into the categories highlighted in Table 1. For example, the impacts of the Elwha River dams on anadromous fish species are discussed by Wunderlich et al. (1994) and Pess et al. (2008). Similar impacts of dams on anadromous species in other systems have been reported in the Clearwater River in Idaho (Wallace and Ball 1978), the Little Salmon River in New York (Meixler et al. 2009), and multiple reaches of the Columbia River in the Pacific Northwest (Magnuson et al. 1996, Dauble and Geist 2000). Historical benefits provided by the Elwha River dams are also similar to those provided by other dams in the USA (e.g. hydropower). More importantly, the removal of the Elwha River dams and others in the USA has been facilitated by the lack of benefits the dams currently provide. Thus, the benefits listed in Table 1 can, in many cases, be described in a historical context and do not contribute significant value to many existing dams in the USA. The current trend towards dam removal, therefore, exemplifies the lack of benefits provided by many dams in the USA (Born et al. 1998, Katopodis and Aadland 2006).

2.2 China: a developed and growing nation

2.2.1 Dam development in China

China’s domestic dam industry is unrivalled at the international level in a number of projects, financial investment, and impacts on the environment and society. Almost half of the world’s 45,000 large dams have been built or are under construction in China (Fuggle and Smith 2000). Additionally, loss of land and environmental degradation caused by dam projects has imposed significant costs on the Chinese rural population. Jing (1997) stated that 10.2 million people living in rural environments had been displaced by hydropower projects by the 1990s. More alarmingly, in his 2007 work report to the National People’s Congress, Premier Wen Jiaboa reported that 23 million people have been displaced by dam projects. China’s most recent five-year plan (2011–2015) has proposed an increase in the number of domestic dam projects by 50% to contribute 130–140 GW to the country’s energy supply.

Assessments of dam projects in China have indicated that the industry has significantly expanded in recent years (Shui 1998, McDonald et al. 2009). The emergence of privately owned
investment firms and the increasing power of local governments have created a more flexible dam industry that is less constrained by bureaucratic limitations and under diminishing control by the central government (McDonald 2007). This decentralization has been attributed to the emergence of China’s market-based economy near the turn of the century (Magee 2006, McDonald 2007, Tullos et al. 2010). China’s government has historically maintained a poor record of transparency in dam development projects, although recent trends indicate a shift towards increasing disclosure, perhaps in acknowledgement of the need to adopt more sustainable approaches (McDonald et al. 2009, Zhang et al. 2010). However, environmental and societal impacts of dam projects remain prevalent; in addition to the lack of control China’s government has in a decentralized market.

Understanding the demographics and ethnicity of Chinese society can also provide insight into initiatives that affect dam development projects and distribution of wealth. A majority of the country’s ethnic diversity is contained in the less-developed interior, as compared to the developed coastal regions. Recent government initiatives such as the Western Development Campaign have focused on developing infrastructure for resource acquisition in China’s interior to meet the growing energy demand from developed areas (Magee 2006, Wei and Fang 2006). These initiatives have profound implications for China’s rural inhabitants as the majority opinion favours development projects as a means to bring these individuals ‘into the twenty-first century’ in line with the country’s broader economic objectives (McDonald 2007).

### 2.2.2 Challenges to sustainable dam development and preservation of livelihood

Several challenges have prevented effective implementation of China’s environmental laws. Two laws affect how hydropower projects are developed and what mitigation activities are conducted. First, the 1988 Water Law states that China’s water resources are owned by the people, whereas important decisions that affect these resources fall under the oversight of government representatives from multiple agencies. The increasing flexibility of China’s dam industry has substantially limited the ability of individuals to participate in decision-making processes implicit in Water Law (Boxer 2001, McDonald 2007). Second, the 2003 Environmental Impact Assessment (EIA) law established a legal requirement for dam developers to assess and alleviate negative impacts of projects. However, EIA law has not been effectively implemented due to lack of requirements for assessing project alternatives, lack of formal mechanisms for including individuals in decision-making, and non-existent provisions for ensuring mitigation measures are met (McDonald 2007). Provisions to improve EIA law were proposed in recent years to support mechanisms for public participation in EIA activities (McDonald et al. 2009).

Oversight of dam development projects is vested in multiple government agencies acting at different levels of organization. Activities that affect resource development and use are under the jurisdiction of several state agencies, including the Ministry of Water Resources, State Environmental Protection Agency, and State Electricity Regulatory Commission. These agencies respond directly to the National People’s Congress, whereas the State Council maintains oversight and also has final authority for approving ‘large’ projects on ‘important’ rivers (Tullos et al. 2010). For smaller projects, the authority is delegated to lower resource management agencies that have recently indicated a realignment of mission objectives towards more sustainable approaches to development, which is reflective of initiatives at higher levels of government (see Fan 2006). The complex bureaucratic structure of China’s government may prove
Box 2: Three Gorges Dam
The TGD on the Yangtze (Chiang Jiang) River is the world’s largest hydropower plant and one of the most controversial infrastructure projects undertaken by a single government. Primarily proposed for energy generation, flood control, and to increase trade routes to Western China, the TGD became fully operational in 2008, generating an electric potential of 18,200 MW and providing a reservoir spanning over 600 km (CTGC 2002). While many of the negative impacts of the project are not yet apparent, substantial degradation of the environment has already occurred and has been compounded by the involuntary resettlement of at least 1.5 million individuals (Jackson and Sleigh 2000, Kittinger et al. 2009).

Many environmental impacts of the TGD project have been documented (Ding et al. 2008, Kittinger et al. 2009, Yi et al. 2010). The Yangtze River Basin supports approximately 350 fish species, 112 of which are endemic and potentially threatened by loss of habitat caused by the dam (Park et al. 2003). Several notable species, such as the river sturgeon (Acipenser dabryanus), Chinese sturgeon (Acipenser sinensis), and Chinese paddlefish (Psephurus gladius), have become increasingly rare as hydropower projects have contributed to habitat loss, in addition to declines from overfishing (Wei et al. 1997, Wu et al. 2004). Mammalian diversity of the Yangtze has also been impacted. Repeated surveys for the Yangtze River dolphin (Lipotes vexillifer) have been unsuccessful in locating a single individual (Turvey et al. 2007). Additional environmental impacts are anticipated downstream of the TGD as a result of reduced flows, such as decreased nutrient transport and regression of riparian wetlands (Lopez-Pujol and Ren 2009). The TGD project has also negatively affected terrestrial environments, primarily from inundation of the reservoir. In addition to several rare plant species that have been impacted by the reservoir (Huang 2001), habitat fragmentation has occurred through the creation of ‘landbridges’ that were previously connected to the mainland (Wu et al. 2003).

The reservoir has caused substantial societal impacts by inundating 11 county towns, and 114 townships, in addition to 1350 small villages where a majority of residents have pursued agrarian or subsistence lifestyles enabled by the Yangtze’s fertile riparian areas (Jackson and Sleigh 2000, Jim and Yang 2006). Increased demand for food is expected with loss of farmland because crops requiring fertile soils and heavy irrigation are staple foods for the affected peoples (Peng et al. 2009). The preservation of an agrarian lifestyle has only been promised to 60% of resettled farmers, although allocated lands for resettlement have been inadequate to fully support agriculture (Jackson and Sleigh 2000, Jim and Yang 2006). Downstream inhabitants will also be disadvantaged by altered geochemical characteristics of the reduced flow system (Yang et al. 2007). Finally, increased occurrences of landslides on the slopes of the reservoir following inundation have created numerous safety hazards (Wu et al. 2001, Liu et al. 2004), particularly for densely populated areas surrounding the reservoir (Yin et al. 2010).

2.2.3 Review and analysis
Box 2 highlights the prominent impacts of the largest dam project in the world to date. Despite the unprecedented nature of the project, the impacts attributed to the TGD are indicative of broad trends observed for dam projects in China (Table 2). The negative impacts of dam projects in China are similar to other regions (e.g. decline of fisheries, relocation from affected areas, etc.) but differ in the sheer magnitude of the impacts, given the number of large dams in the country. For example, current estimates have indicated that as many as 23 million people have been displaced by large dams in China (see above). The number of displaced individuals is second only to India (WCD 2000) and is not only related to the size of dam projects, but also the population densities of affected areas, particularly the Yangtze River Basin. Other unique impacts attributed to dam projects in China have also been observed. For example, a unique environmental cost of dam projects that has relevance to both social and environmental concerns is the potential impacts large reservoirs have had on geological stability. In addition to nearshore landslides, large reservoirs have been associated with tectonic instability (Goldsmith and Hildyard 1984, pp. 104–119). Of particular interest is the potential role the Zipingpu reservoir may have had in the catastrophic 2008 Wenchuan earthquake. Although the specific role remains controversial, studies have not excluded the reservoir as one of several contributing factors that may have caused the earthquake (Ge et al. 2009, Lei 2011). Similar concerns have been raised for the potential impact that the TGD reservoir may have on regional geological stability (Chen and Talwani 1998).

The benefits described in Table 2 have provided a strong rationale for the proliferation of dam projects, particularly because of the country’s rapid economic growth in recent years. While dams in other regions of the world are constructed for similar reasons, China’s increasing economic and population growth have created tremendous demand for energy, water security, and to a lesser extent, flood control. Understandably, dams have also been advocated by proponents as a means to improve navigation and trade, particularly by allowing increased access to interior regions of the country (Peng et al. 2010). Regardless of whether the claimed benefits provided by dams are fulfilled, the unique geopolitical climate of China provides an interesting context within which to analyse the role of dams in society. The proposed benefits are certainly noteworthy as one cannot provide an argument, for example, against the loss of life prevented by damming an unpredictable river. However, the far-reaching negative impacts of dams balanced with their proposed benefits bring into question the overall sustainability of dams in China. Current debates regarding social equity and
economic development have focused on the relative tradeoffs of large infrastructure projects, with no clear consensus on the most appropriate methods for achieving sustainable development (Jackson and Sleigh 2000, Boxer 2001).

2.3 SE Asia: environment, livelihoods, and politics in a developing region

2.3.1 Brief history of hydropower development in the Mekong River Basin

Hydropower development was first considered in SE Asia by the Mekong Committee, an intergovernmental agency established in 1957 to represent the interests of Thailand, Laos, Vietnam, and Cambodia. The Mekong Committee was backed by the United Nations with considerable financial and technical support from the USA (McCully 2001, Molle et al. 2009). Technical advisors from the US Army Corps and the Bureau of Reclamation advocated hydropower to promote economic growth of the region (Middleton et al. 2009), and secondarily to pre-empt the spread of communism through infrastructure development (Middleton et al. 2009, Hirsch 2010). Additionally, the prevailing technocentric approaches to integrated river basin development promoted by the United Nations presumably considered infrastructure development as an efficient and effective approach to alleviating poverty (Saha and Barrow 1981). With the exception of Thailand, hydropower development halted as a wartime conflict pervaded the region, until the 1990s when a relative level of stability was regained.

International development banks and private-sector companies have also promoted infrastructure development in SE Asia. The World Bank and the Asian Development Bank (ADB) promoted hydropower development in the 1990s to improve regional infrastructure (IRN 1999, Bourdet 2000), especially in Laos with its numerous Mekong tributaries and mountainous topography. Laos’ nominal infrastructure development, mainly rural populace, and low quantifiable economic capital provided justification for development banks to promote mandates of poverty reduction through hydropower development. Although the development banks require some level of environmental and social review, the effectiveness of top-down approaches to reduce poverty are questionable in consideration of the secondary environmental and societal impacts of such projects. More recently, international and regional private-sector companies have promoted dam construction in SE Asia. In particular, Thai and Vietnamese companies are major investors in dam construction both within their respective countries as well as in Laos and Cambodia (Middleton et al. 2009). With less stringent environmental and social review processes, private-sector companies are often more attractive to national governments than multilateral development banks. Currently, over 100 hydropower dams in the Mekong River Basin are operational, under construction, or are proposed to be built in the near future (Hirsch 2010, ICEM 2010).

2.3.2 Environmental and social impacts of hydropower development in SE Asia

The Mekong River Basin supports a high level of endemism and is recognized as a global biodiversity hotspot (CEPF 2007, Koh and Sodhi 2010). The Mekong River is second only to the Amazon River in fish species diversity (Woodruff 2010) with over 700 fish species identified to date, and an estimated 1300 within the entire basin (Baran et al. 2007). The Mekong Basin also provides critical habitat for a number of endangered species, including giant Mekong catfish (Pangasianodon

Table 2. Impacts of dam projects and literature sources for China.

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Type</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decline of aquatic organisms</td>
<td>P, C, S</td>
<td>Park et al. (2003), Wu et al. (2004), Wei and Fang (2006), Turvey et al. (2007), and Yi et al. (2010)</td>
</tr>
<tr>
<td>Decline of fisheries</td>
<td>P, C</td>
<td>Wei et al. (1997), Jackson and Marmulla (2001), and Kang et al. (2009)</td>
</tr>
<tr>
<td>Decline of terrestrial organisms</td>
<td>P, C, S</td>
<td>Huang (2001), Ding et al. (2008), Lopez-Pujol and Ren (2009), Fu et al. (2010), and Zhang et al. (2011)</td>
</tr>
<tr>
<td>Geological instability from reservoir</td>
<td>P, C</td>
<td>Chen and Talwani (1998), Wu et al. (2001), Liu et al. (2004), and Yin et al. (2010)</td>
</tr>
<tr>
<td>Loss of culture and social disintegration</td>
<td>C</td>
<td>Tan et al. (2005), Wei and Fang (2006), McDonald (2007), and Kittinger et al. (2009)</td>
</tr>
<tr>
<td>Reduction of downstream flows</td>
<td>R, S</td>
<td>Yang et al. (2007) and Lopez-Pujol and Ren (2009)</td>
</tr>
<tr>
<td>Relocation from affected areas</td>
<td>C</td>
<td>Jing (1997), Jackson and Sleigh (2000), Heming et al. (2001), and McDonald et al. (2008)</td>
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<tr>
<td>Benefits</td>
<td></td>
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</tbody>
</table>

Notes: Impacts are described as costs or benefits and further defined based on the type of ecosystem service that is affected (P, provisional; R, regulating; C, cultural; S, supporting; from MEA 2003). Both costs and benefits are provided to facilitate qualitative evaluations of projects in each region.

*Supplementary sources are provided in addition to sources in the main text.
gigas), Irrawaddy dolphin (Orcaella brevirostris), Cantor’s giant softshell turtle (Pelochelys cantorii), black-bellied tern (Sterna acuticauda), greater adjutant (Leptoptilos dubius), and large-antlered muntjac (Muntiacus vuquangensis) (Claassen 2004, Bezuijen et al. 2008, WCS 2009). Moreover, new species are routinely discovered in the region (Duckworth et al. 2001, Dersu and Associates 2007, Bezuijen et al. 2008).

Estimates from the International Rivers Network and United Nations indicate that the Mekong River Basin is home to 60 million people (IRN 2008, UNESCAP 2011), most of whom are rural inhabitants that practice a mix of subsistence agriculture, fishing, livestock husbandry, hunting, and gathering of non-timber forest products (Shoemaker et al. 2001, CEPA 2007, Blake et al. 2009). Of particular concern for local livelihoods are the potential impacts of hydropower development on Mekong fisheries. The Mekong River Basin supports the largest inland fishery in the world (Sarkulla et al. 2009), with an estimated annual value of US $2–3 billion (Baran et al. 2007). A third of the human population in the Mekong Basin is involved in fishing, such that fish comprise 40–80% of people’s daily protein intake, with non-fish aquatic organisms such as crabs, shrimp, clams, and snails contributing an additional five percent (Touch and Todd 2001, Hortle 2007).

Several dams in the region have caused significant declines in fish populations and consequently to people’s livelihoods and food security. Fish harvest on the Sesan River in Cambodia has decreased for 30–60% since construction of the Yali Falls Dam upstream in Vietnam (Baird and Meach 2005). Degradation of fish habitat and migration barriers caused by the Pak Mun Dam in Thailand contributed to significant declines in fish populations, leading to massive protests by the local people. These protests prompted government restitutions, installation of a fish ladder, stocking of the reservoir, and opening of the dam gates for four months each year to allow fish passage (Roberts 2001, Foran and Manorom 2009). However, 91 of 240 documented fish species have disappeared in the Mun River since dam construction and only two species have been observed using the fish ladder (Roberts 2001). No fish ladders in SE Asia have been successful in allowing passage for more than a few species (Roberts 2001).

The flood pulse hydrology of the Mekong River Basin plays an important role in maintaining ecosystem and agricultural productivity (Woodruff 2010). The natural timing of high flow events is critical to the life histories of many Mekong fishes (Dudgeon 2000, Shoemaker et al. 2001, Woodruff 2010). Additionally, flooding provides fertile soil for rice and agriculture by depositing sediment in the flood plain and delta. Although flood control is an important justification for dam construction, inhabitants of the Mekong Basin have adapted their lifestyles to accommodate annual flooding and are not necessarily negatively impacted by flooding events. On the contrary, the benefits of flooding to local livelihoods potentially outweigh the costs associated with occasional crop and property destruction by providing nutrients for agriculture and maintaining important ecosystems (Shoemaker et al. 2001, Lebel et al. 2005).

Downstream changes to hydrology and sediment transport and the subsequent environmental and societal impacts caused by dams have received only cursory attention by dam proponents. An environmental impact study conducted for the Yali Falls Dam in Vietnam covered only a 7 km stretch downstream of the dam (Halcrow and Partners 1998), yet negative impacts to wildlife and human livelihoods were documented hundreds of kilometres downstream in Cambodia (Claassen 2004, Baird and Meach 2005). This case highlights the inadequacies in accounting for the costs of hydropower, as well as issues of transboundary politics. Additionally, most of the affected Cambodians are indigenous minority groups who were not consulted prior to development and also do not have political leverage to lobby support from the Cambodian government (Baird et al. 2002, Kim and Tep 2006).

A majority of dams in the Mekong Basin have been built on tributaries to the mainstream. However, since 2006 there has been renewed interest in mainstream dams, with 12 dams proposed in SE Asia (10 in Laos and 2 in Cambodia) (Hirsch 2010, ICEM 2010). In 2009, the Mekong River Commission (MRC), established to foster cooperation in development projects among nations in the Mekong Basin, commissioned an independent review of the proposed projects. The October 2010 report recommended a 10-year moratorium on building mainstream dams to allow for more thorough review of potential costs and benefits (ICEM 2010). The report was also commissioned partly in response to the proposed Xayaburi Dam in Laos. Opposition to the project from regional and international non-governmental organizations (NGOs), as well as from the governments of Cambodia and Vietnam, resulted in a construction delay of the dam until concerns about the project’s environmental and social costs can be better addressed. Although these recent events indicate a shift towards more sustainable development practices in SE Asia, the future of Mekong mainstream hydropower development remains uncertain.

Box 3: Nam Theun 2 (NT2)

The NT2 project in Laos is a transbasin diversion project consisting of a 39 m dam on the Theun River and a 450 km² reservoir flooding about half of the Nakai Plateau. Water is shunted from the reservoir down a 350 m escarpment into the Xe Bang Fai River via a 27 km long channel, thus impacting two major rivers in two separate basins. Conservation priority species that have been impacted by the project include Asian elephant (Elephas maximus), large-antlered muntjac (M. vuquangensis), white-winged duck (Cairina scutulata), otter, and turtle species. At least five new rodent and two fish species were documented during a pre-inundation survey (Dersu and Associates 2007). Additionally, approximately 6200 people were relocated from the inundation zone and an additional 120,000 people on the Xe Bang Fai River suffered livelihood losses (Shoemaker et al. 2001, Lawrence 2009).

NT2 was touted by the World Bank and ADB as exemplary in its treatment of environmental and social concerns. However, several mitigation measures for the NT2 hydropower project were inappropriate, unrealistic, or poorly implemented (Dersu and
Social mitigation measures have also been inadequate. Although affected individuals were promised monetary compensation prior to the commencement of the project, funds were not distributed until several years after project initiation. Additionally, an alternative livelihood development plan was implemented because of shortages in replacement lands and impacts to fisheries, which included training and support for upland rice and cash crop cultivation. However, the International Rivers Network has reported that the poor quality of resettled lands has prevented the cultivation of crops and the non-existence of local markets for selling cash crops has prevented individuals from obtaining sufficient income (IRN 2008). On the Xe Bang Fai River, a micro-credit fund was created for affected individuals to invest in alternative livelihood developments. Although the fund has provided monetary support for affected individuals, high interest rates and the need to repay loans when alternative livelihood ventures were unsuccessful has created a disincentive for borrowing (IRN 2008, Lawrence 2009).

2.3.3 Review and analysis

Inadequate environmental, social, and economic assessments have contributed to the lack of sustainability of many hydropower projects in SE Asia. Benefits from hydropower have also been exaggerated, such as for the Pak Mun Dam, which had an estimated electricity generation potential that was nearly five times greater than the actual amount (Roberts 2001, Foran and Manoron 2009). Transboundary impacts of river development also pose challenges as upstream countries often do not account for downstream impacts. National governments, the MRC, multilateral lending agencies, and private-sector companies have also inadequately addressed damages to the environment and local livelihoods (Shoemaker 1998, IRN 1999, Baird et al. 2002, Sneddon and Fox 2007). Additionally, lack of transparency and poor participatory processes have caused difficulties for dam-affected people to have a meaningful dialogue with decision-makers regarding hydropower development (IRN 1999, Baird et al. 2002, Sneddon and Fox 2007). Corruption by multilateral donor agencies, national, provincial and local government agencies, and private-sector dam consultants and construction companies have also presented obstacles to more sustainable development (IRN 1999, McCully 2001, IRN 2008). Finally, mitigation measures against hydropower projects have often been inappropriate, unrealistic or poorly executed (Box 3).

The NT2 project represents a progressive initiative to account for the full costs of hydropower development and suggests a greater awareness by development firms of the need to account for social and environmental externalities (Table 3). Box 3 highlights some of the initiatives undertaken to mitigate the environmental and social impacts of the NT2 project. However, the success of these initiatives in achieving sustainable development remains questionable, particularly in light of the challenges that have been encountered in their implementation. The underlying causes that create challenges to sustainable development in developing countries (e.g. balancing poverty alleviation with economic growth) have not been effectively addressed. For example, the implementation of alternative livelihood plans has been insufficient for ensuring affected individuals are not adversely affected.

<table>
<thead>
<tr>
<th>Impacts</th>
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</tr>
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<tbody>
<tr>
<td>Decline of fisheries</td>
<td>P, C</td>
<td>Baird and Meach (2005), Khoa et al. (2005), and Dugan et al. (2010)</td>
</tr>
<tr>
<td>Reduction of downstream flows</td>
<td>R, S</td>
<td>Baird et al. (2002), Claassen (2004), and Baird and Meach (2005)</td>
</tr>
<tr>
<td>Relocation from affected areas</td>
<td>C</td>
<td>Shoemaker (1998) and Lawrence (2009)</td>
</tr>
<tr>
<td>Electricity generation</td>
<td>P, R</td>
<td>Hirsch (2010), ICEM (2010), and Kosa et al. (2011)</td>
</tr>
<tr>
<td>Flood control</td>
<td>R, S</td>
<td>Lebel et al. (2005) and Richaud et al. (2011)</td>
</tr>
<tr>
<td>Poverty alleviation</td>
<td>C</td>
<td>Kloeppe (2008) and Lawrence (2009)</td>
</tr>
</tbody>
</table>

Notes: Impacts are described as costs or benefits and further defined based on the type of ecosystem service that is affected (P, provisional; R, regulating; C, cultural; S, supporting; from MEA 2003). Both costs and benefits are provided to facilitate qualitative evaluations of projects in each region. 

Supplementary sources are provided in addition to sources in the main text.
impacted. Resettlement lands have been in short supply and alternative livelihood ventures have been ineffective because of the lack of congruency with traditional means of livelihood. Moreover, the lack of transparency and accountability exhibited by private development firms highlights the fundamental disparity between traditional economic approaches to development and progressive approaches that seek to achieve sustainability. Many of the costs and benefits of dams in SE Asia that apply to NT2 can also be extended to other projects (Table 3), and perhaps have not been effectively addressed because of difficulty of their valuations in traditional economic paradigms.

3 Discussion

3.1 Understanding the development gradient

The fundamental challenges to more accurate and holistic cost–benefit analyses are not unique to examples in this review. Additionally, our analysis indicates that costs and benefits are similar for each region (Tables 1–3). Dams have severely degraded aquatic systems and imposed considerable social costs, regardless of region. What information is, therefore, gained by examining dam projects in the USA, China, and SE Asia? How can this information be used to develop a broader understanding of how and why these projects continue to persist at different levels of economic development? To address these questions, the relationship of economic growth, the environment, and society must first be examined. Our review illustrates a distinct temporal component of economic development that dictates policies and governance mechanisms to mitigate environmental and social costs of infrastructure projects. That is, sufficient policies and governance mechanisms for environmental protection are often not implemented until after a country is developed. Indeed, economic indicators, such as gross domestic product, can predict effects of development on the environment such that the relationship can be described by an inverted-U or environmental Kuznets curve (Selden and Song 1994). Environmental degradation increases with economic growth until a maximum point is reached, after which degradation decreases with further growth as substantial institutions for environmental protection are established (e.g. multijurisdictional resource management agencies or effective legislation). While the environmental Kuznets curve has been applied to many scenarios describing the relationship between economic development and environmental degradation (e.g. emissions, Selden and Song 1994, Dinda 2004), to our knowledge, the curve has not been applied to the case of dams. Examples from the three regions in the context of the environmental Kuznets curve are indicated in Figure 1.

To better understand the relationship of economic development with environmental degradation in the context of dams, slight modifications to the environmental Kuznets curve can be made so the curve follows a bell-shape rather than an ‘inverted-U’. That is, environmental degradation caused by dams increases at an increasing rate as a country progresses in development status away from point 1, and decreases at a decreasing rate as a country approaches developed and moves towards point 3. The relationship between the two axes in Figure 1 can be modelled using the probability density function for the standard normal distribution (note the equation represents the shape, not a probability distribution):

$$f(x) = \frac{1}{\sqrt{2\pi}} \cdot \exp\left(-\frac{x^2}{2}\right), \quad (1)$$

where $f(x)$ represents environmental degradation as a function of an economic development indicator, $x$. Figure 2 provides an alternative depiction of the relationship between economic development and environmental degradation, using a slight

Figure 1. Theoretical relationship of economic development and environmental degradation from Eq. (1). Economic development is measured using an indicator (e.g. per capita gross domestic product) and environmental degradation is measured by loss of ecosystem services and livelihoods. The illustrated relationships represent ideal scenarios, such that SE Asia, China, and the USA exemplify broad trends consistent with the general relationship.
modification to Eq. (1). Suppose an additional variable is defined, ‘environmental capital’, which is inversely related to environmental degradation and can also be described as a function of economic development. The relationship between environmental capital and economic development can be described by taking the integral of Eq. (1) and multiplying by negative one:

\[
g(x) = -1 \cdot \int f(x) \, dx = -1 \cdot \left( \frac{1}{\sqrt{2\pi}} \right) \cdot \exp \left( -\frac{x^2}{2} \right) \, dx, \quad (2)
\]

where \( g(x) \) represents environmental capital as a function of the same economic development indicator, \( x \), used in Eq. (1). Figure 2 illustrates this relationship and provides an alternative depiction of Figure 1, whereby the rate of environmental degradation is increasing for developing countries (point 1, SE Asia), maximized at moderate levels of development (point 2, China), and decreasing for developed countries (point 3, USA). Environmental capital also decreases across the development gradient and partly explains current trends in development in the three regions. For example, dams are currently advocated in SE Asia due to high environmental capital, whereas dam projects in the USA are not a current focus of development as a majority of viable projects have already been pursued (i.e. low environmental capital). The integration used to produce Figure 2 can also be described as the cumulative loss of environmental capital across the development gradient. As a country progresses from undeveloped to developed, the environmental capital of domestic resources is cumulatively depleted as economic growth progresses, until insufficient resources are available to sustain continued growth. The current trend towards dam removal in the USA suggests the cumulative loss of environmental capital is approaching 100% (in the context of damming rivers) and removal of dams can restore environmental capital or ecosystem services. Finally, Figure 2 illustrates the inverse relationship of environmental capital and policy effectiveness, such that as economic development increases, environmental capital is diminished whereas policy effectiveness becomes maximized.

In summary, Figures 1 and 2 illustrate the theoretical relationships of economic growth with environmental degradation, capital, and policy effectiveness in three distinct phases of development. First, SE Asian countries are developing and have non-existent or ineffective mechanisms in place to enforce environmental standards (although multilateral banks advocate use of such standards). The potential environmental capital is also maximized such that vast quantities of unused resources continue to promote development. Second, China has a transitional economy such that the country has experienced increasing development as a result of recent economic reforms. This development is mirrored by the rate at which domestic dam projects are being pursued by local governments and private development firms. Indications at upper levels of the Chinese government have suggested recognition of the need to consider full costs of development projects, although sustainability has yet to be achieved (i.e. emerging policy effectiveness in Figure 1). Third, the USA is developed and has arguably the most effective policies and governance mechanisms among the regions for ensuring environmental protection (e.g. ESA, Clean Water Act, etc.). However, the lack of environmental capital that is available for resource acquisition through dam projects has contributed to the increasing number of dams that have been removed or are scheduled for removal.
3.2 Drivers of dam projects

The relationship of economic development and environmental protection illustrated by Figures 1 and 2 facilitates an understanding of development paradigms in each of the three regions. However, this relationship is superficially correlative and warrants a more detailed assessment of the fundamental drivers that influence development paradigms. The complexities of the political-ecology dimension (i.e. political environments in which decisions have ecological consequences) have profound influences on infrastructure projects, which has relevance in the context of a region’s economic development status. Indeed, the fundamental drivers of dam projects, either for construction or removal, are largely the product of prevailing attitudes regarding the perceived benefits or costs of such projects, regardless of actual empirical evidence for or against a project (Rigg 1991, Johnson and Graber 2002). This suggests that even more accurate cost–benefit analyses, although a fundamental first step towards more sustainable development, will carry little weight in combating the political will behind a project. The political pressure that proponents of dam projects have on decisions can be substantially disproportionate to the critics, particularly in developing countries when international financiers are involved (Middleton et al. 2009). Proponents of dams in developing countries carry strong arguments that dams will provide electricity, agricultural irrigation, and prevent loss of life from flooding. Critics that argue projects are environmentally or socially harmful are therefore easily dismissed, for example, as individuals that would ‘deny their fellow men the fruits of progress for the sake of a few wild animals’ (Goldsmith and Hildyard 1984, p. 55). Despite these strong arguments, many of the benefits claimed by project proponents are also not fulfilled or are grossly exaggerated. For example, electricity potential of hydropower dams is often stated as being higher than actual amounts after project completion (Foran and Manorom 2009), reservoir fisheries claimed to benefit local populations fail to become established (Kittinger et al. 2009), or the increased production of crops from irrigation by dams fails to alleviate local hunger (Goldsmith and Hildyard 1984). The political will behind infrastructure development projects often fails to consider these past lessons; projects are initiated with the assumption that they will be completed regardless of fallbacks, thus providing strong deterrents against abandoning a project on the grounds of pre-emptive cost–benefit analyses.

The prevailing attitudes and political will for promoting dam projects in developed countries, either for construction or removal, is drastically different from those in developing countries. The relationship between drivers of projects and the political-ecology dimension can in part explain the emergence of environmental and social protection measures with economic development illustrated in Figure 2. However, an important point is that large infrastructure projects were historically promoted in developed countries for many of the same reasons that proponents continue to advocate dams in developing countries. Therefore, recognition that many dams in developed countries no longer serve purposes for which they were built or failed to provide claimed benefits is fundamental to understanding the political will for discouraging additional projects or removing defunct dams. Common social problems that are used to garner support of dams in developing countries (i.e. flood control, electricity generation, etc.) no longer provide sufficient justification for the continued construction of infrastructure in developed countries. Additionally, the US environmental movement facilitated a shift in public opinion that viewed the industrial complex as environmentally exploitative and realized the limits of human activity (Dunlap 1991). This paradigm shift in ideology towards more environmentally-oriented opinions is arguably related to the basic requirements of society and individual well-being, fulfilled in part by the historical contributions of infrastructure projects, such as dams. Gradual shifts in opinion regarding matters of importance, such as a recognition of an individual’s relationship with the environment (Leiserowitz et al. 2006), was facilitated by comparatively high standards of living. This is not to suggest individuals in developing countries who follow subsistence lifestyles have little value for the environment, rather the evolution of societal opinion in favour of the natural environment often follows post-industrialization. The influence of these opinions on environmental matters in the USA, particularly regarding dam removal, has taken the forefront in debates of societal use of natural resources (Born et al. 1998, Johnson and Graber 2002).

3.3 Methods of change

The engenderment of a political atmosphere in favour of environmental and social protection suggests degradation of the natural resource base is a necessary prerequisite of economic development that facilitates shifts in opinion regarding the efficacy of dam projects. The externalities imposed on the environment and marginalized segments of society by large infrastructure projects, therefore, appear to be inevitable consequences of economic development. However, an assessment of the limited examples of dam projects that have been cancelled or re-evaluated for sustainability can provide insight into how these projects can be prevented, if costs exceed benefits or improved to more adequately mitigate externalities, respectively. The political power of affected individuals in developing countries has been shown to be paramount in the process for addressing externalities of dam projects. For example, Rigg (1991) assesses the emergence of an environmental movement in Thailand and the potential role in preventing construction of the Nam Choan Dam. Rigg (1991) suggests that the indoctrination and organization of local populations is perhaps the most effective means of mitigating the effects of dam projects. This does not suggest that projects should be adamantly opposed by affected parties, but rather the negative externalities should be priority mitigation activities addressed by developers, made possible by providing an active political voice to affected peoples. A potentially useful indicator
of the political will of historically under-represented individuals is the rise of NGOs. McDonald (2007) suggests that the rise of NGOs and the will of local peoples have created an effective means of stalling efforts to dam the Nu River in China. While the lobbying power of NGOs in China is not without limits, the increasing role NGOs have had in the discussion of current dam projects suggests an emergence of more proactive environmental protection measures. This emergence is necessary to more sustainably develop the country’s resources, having implications for development activities elsewhere.

A more empirical approach to account for the negative externalities of dam projects is their explicit valuation as services provided by ecosystems. Regardless of the potential challenges associated with the use of ecosystem services (e.g., institutional barriers and accurate quantification), our analysis contributes to the growing body of literature that advocates ecosystem services as a useful approach for more holistic evaluation of costs and benefits. A recent study conducted by Brown et al. (2009) illustrated the development of the Integrated Dam Assessment Modelling (IDAM) tool as an approach to holistically evaluate dam projects in a multidisciplinary perspective. The IDAM allows for the integration of biophysical, socio-economic, and geopolitical perspectives into a single cost–benefit analysis, accounting for both objective and subjective measures. Therefore, the IDAM could be particularly useful in the comparison of ecosystem services because it combines subjective measures of valuation with more tangible costs or benefits. To date, the IDAM has not been fully implemented as a tool for more holistic cost–benefit evaluations (but see Tullos et al. 2010) because of its recent introduction. However, other researchers have recently advocated the use of similar multidisciplinary approaches as a means to more accurately assess costs and benefits of dam projects. Kittinger et al. (2009) recently conducted a holistic evaluation of the TGD project with an emphasis on linking ecological change and human well-being. The approach, therefore, relies heavily on the basic principles of ecosystem services and provides a more detailed understanding of how development affects human livelihoods through ecosystem degradation. Our analyses contribute to the growing body of literature illustrated by Brown et al. (2009) and Kittinger et al. (2009) that promote more holistic evaluation of costs and benefits, primarily through the quantification of ecosystem services. For example, Tables 1–3 describe broad impacts of dam projects on ecosystem services for each region, which are also amenable for more detailed analyses, such as the approach illustrated by the IDAM. Accurate comparisons of costs and benefits are a necessary first step towards more sustainable development.

3.4 Conclusion

Assessments of dam projects in the USA, China, and SE Asia have illustrated problems for effective environmental protection and maintenance of livelihoods for affected peoples. These regions were chosen to exemplify societal and political challenges to sustainability in the context of different development trajectories. Furthermore, our assessment of dam projects indicates a need to adopt more sustainable approaches to development that have been advocated by several authors (Goodland et al. 1993, McDonald 2007, Brown et al. 2009, Kittinger et al. 2009). A general conclusion can be made that suggests, in addition to more holistic cost–benefit analyses, dam developers and financiers need to establish more accountability and transparency. Explicit mechanisms also need to be in place to allow affected individuals and stakeholders an active voice in decisions for projects, including both dam construction and removal. The relationship between economic development and environmental degradation illustrated in Figures 1 and 2 should provide a context within which to frame development paradigms that consider the potentially conflicting roles of policy implementation and environmental capital.

The implementation of more thorough cost–benefit analyses conducted at the onset of project development could improve protection of the environment and local livelihoods. Cost–benefit analyses should accurately reflect costs of dam projects throughout a dam’s entire lifespan, as well as include multiple spatial and temporal contexts. The most apparent need to improve cost–benefit analyses is to provide an explicit link between development and loss of livelihood through degradation of the environment. Such an approach could rely heavily on principles of ecosystem services, especially those that quantify the loss of services from altered flows. Although not a comprehensive list, these costs should consider losses associated with reduced agriculture from floodplain regression, loss of marine fisheries at river outflows, loss of fisheries upstream, and loss of water supply. Additionally, project assessments need to consider costs from operation and eventual dam removal. Adequate assessment of compensation costs for displaced individuals is also necessary for cost–benefit analyses aimed at sustainable development (Jackson and Sleigh 2000, Jim and Yang 2006). Although our suggestions for more holistic cost–benefit analyses only briefly address a finite number of specific needs, a greater recognition of the costs of dam projects could contribute to more environmentally sustainable approaches to infrastructure development. As indicated above, broader involvement of affected individuals in decision-making processes, facilitated in part by the emergence of a political atmosphere in favour of environmental and social protection, will ensure that dam projects are more equitably implemented.

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