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Biodiversity offsets may miss opportunities to mitigate impacts on ecosystem services

Laura J. Sonter
University of Vermont

Jesse Gourevitch
University of Vermont

Insu Koh
University of Vermont

Charles C. Nicholson
University of Vermont

Leif L. Richardson
University of Vermont

See next page for additional authors

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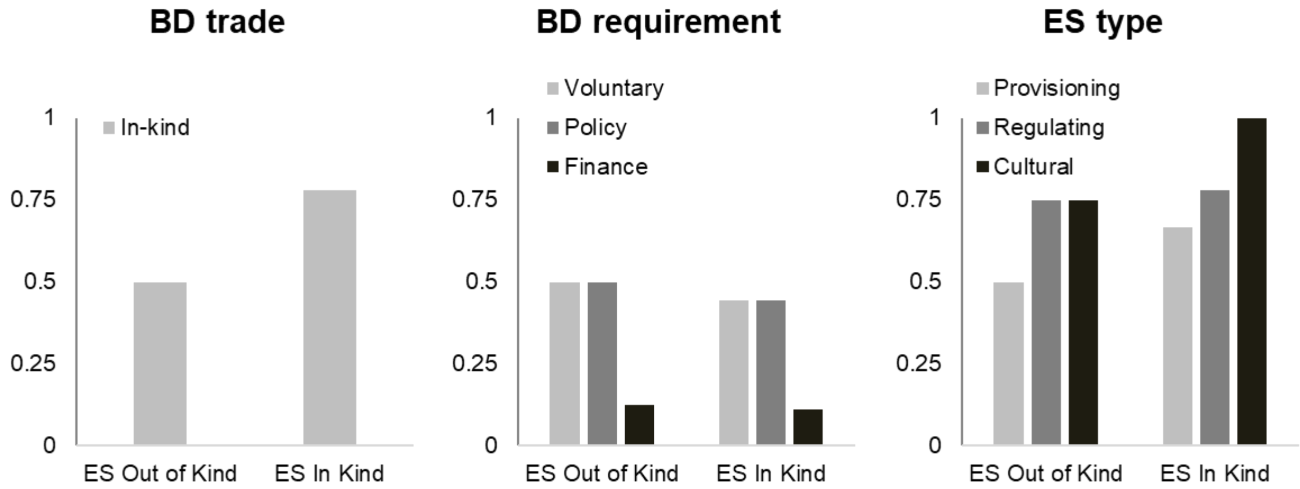
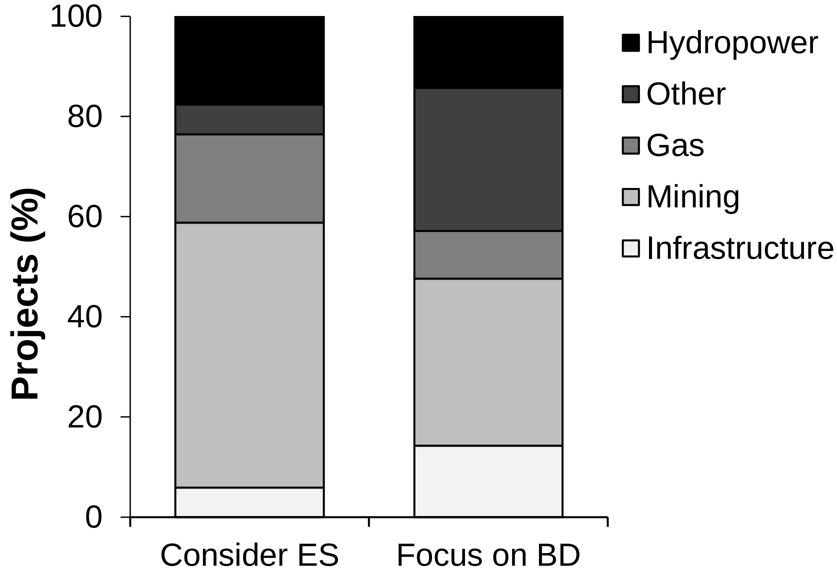
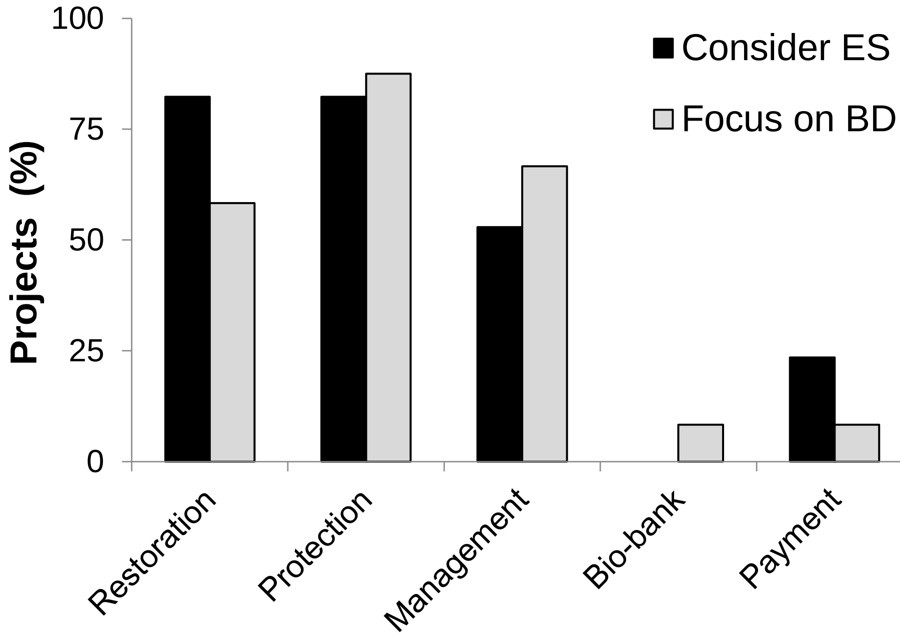
Authors
Laura J. Sonter, Jesse Gourevitch, Insu Koh, Charles C. Nicholson, Leif L. Richardson, Aaron J. Schwartz, Nitin K. Singh, Keri B. Watson, Martine Maron, and Taylor H. Ricketts



WebFigure 1. Comparing offsets that make in-kind (*n* = 9) versus out-of-kind (*n* = 8) ES trades (WebTable 2, Variable 23) in terms of the proportions making in-kind BD trades (WebTable 2, Variable 17), having various BD requirements (WebTable 2, Variable 16), and different ES types (WebTable 2, Variable 21). ES = ecosystem services; BD = biodiversity.



WebFigure 2. Comparing industries (WebTable 2, Variable 4) between offsets that considered ecosystem services (ES; *n* = 17) and those that focused exclusively on biodiversity (BD; *n* = 24).



WebFigure 3. Comparing offsetting approaches between offsets that considered ecosystem services (ES; n = 17) and those that focused exclusively on biodiversity (BD; n = 24). Note: 95% of offsets used more than one offsetting approach, so the sum of the series totals is >100%.

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WebTable 1. Biodiversity offsetting projects.

Project name		Source		Development approved	Offset strategy	Information source			
						EIA		Offset strategy	
						1st	2nd	1st	2nd
1	Akyem gold mine	W	CI (2013); Madsen *et al*. (2010)	Y	Y	N	Y	N	Y
2	Amaila Falls hydropower	W	CI (2013)	N	N	-	-	-	-
3	Ambatovy nickel mine	W L	Bidaud *et al*. (2015) Kormos *et al*. (2014); Madsen *et al*. (2010)	Y	Y	Y	N	Y	N
4	Anglo American Platinum mine	W	BBOP (2009); Madsen *et al*. (2010)	Y	Y	Y	N	N	Y
5	Antamina copper and zinc mine	W	BBOP (2009)	Y	Y	N	Y	N	Y
6	Apennine wind farms	W	BBOP (2009)	Y	Y	N	Y	N	Y
7	Australia Pacific LNG ES offset	W	Madsen *et al*. (2010)	Y	Y	Y	N	Y	N
8	Barrick Gold’s Kanowna Belle	W	Madsen *et al*. (2010)	Y	Y	N	Y	Y	Y
9	Basslink undersea power cable	W L	Bidaud *et al*. (2015) BBOP (2009)	Y	Y	Y	N	N	Y
10	BP oil and gas project, San Juan	L	Sochi and Kiesecker (2016)	N	N	-	-	-	-
11	Brisas copper–gold mine	W	Madsen *et al*. (2010)	N	N	-	-	-	-
12	Bujagali hydropower project	W	BBOP (2009); Madsen *et al*. (2010)	Y	Y	Y	Y	Y	Y
13	Bumbuna hydroelectric project	L	Cole and Dahl (2013)	Y	Y	Y	Y	Y	Y
14	Carbones del Cerrejón	W	CI (2013)	Y	Y	Y	Y	Y	N
15	CEMEX El Carmen Wilderness Area	W	BBOP (2009)	Y	N	-	-	-	-
16	Chad–Cameroon pipeline	W	BBOP (2009) Madsen *et al*. (2010)	Y	Y	Y	N	N	Y
17	Cobre Panama	W L	Kormos *et al*. (2014) ICMM and IUCN 2013	Y	Y	N	Y	N	Y
18	Esso Highlands LNG project	W	CI (2013)	Y	Y	Y	Y	Y	Y
19	Oc’via farmland in southern France	L	Maron (2015)	Y	Y	N	Y	N	Y
20	Gasoduto Bolivia–Brasil pipeline	L	Quintero and Mathur (2011)	Y	Y	Y	N	N	Y
21	Global Alumina project	L	Cole and Dahl (2013)	Y	Y	Y	Y	N	Y
22	Holcim Bardon Hill quarry	W	BBOP (2009)	Y	Y	Y	N	Y	Y
23	Ingula pumped storage scheme	W	BBOP (2009); Madsen *et al*. (2010)	Y	Y	Y	N	Y	Y
24	Jandakot airport development	L	Martin *et al*. (2016)	Y	Y	Y	N	Y	N

Project name		Source		Development approved	Offset strategy	Information source			
						EIA		Offset strategy	
						1st	2nd	1st	2nd
25	Jonah Gas Field	W	Madsen *et al*. (2010) BBOP (2009)	Y	Y	N	Y	N	Y
26	Kate Valley landfill	L	Norton (2009)	Y	Y	N	Y	N	Y
27	Kennecott Utah copper mine	W	BBOP (2009)	Y	Y	N	Y	Y	Y
28	Kumtor gold mine	W	BBOP (2009)	Y	N	-	-	-	-
29	Lom Pangar dam	L	Kormos *et al*. (2014)	Y	Y	Y	Y	Y	Y
30	Manuaus Energia Balbina hydropower	W	BBOP (2009)	Y	Y	N	Y	Y	Y
31	Mount Royal golf estate	W	BBOP (2009); Madsen *et al*. (2010)	Y	Y	Y	N	N	Y
32	Nam Theun 2 hydropower project	W	BBOP (2009)	Y	Y	Y	N	Y	Y
33	Abbot Point Growth Gateway	L	Martin *et al*. (2016)	Y	Y	Y	N	Y	N
34	Pascua Lama	W	BBOP (2009)	N	N	-	-	-	-
35	Pulp United pulp mill	W	BBOP (2009); Madsen *et al*. (2010)	N	Y	-	-	-	-
36	QGC Pty Ltd – Curtis LNG project	L	Martin *et al*. (2016)	Y	Y	Y	N	Y	N
37	QIT Madagascar Minerals	W	Bidaud *et al*. (2015); BBOP (2009); ICMM and IUCN (2013)	Y	Y	Y	N	Y	N
38	Rhenish-Westphalian	W	BBOP (2009)	N	Y	-	-	-	-
39	Rio Tinto Simandou partnership	W L	Kormos *et al*. (2014) Seagle (2012); Virah-Sawmy *et al*. (2014); Madsen *et al*. (2010)	N	Y	-	-	-	-
40	Oyu Tolgoi copper–gold mine	W	ICMM and IUCN (2013); Madsen *et al*. (2010)	Y	Y	Y	N	Y	N
41	Smøla wind farm	L	Cole and Dahl (2013);	Y	N	-	-	-	-
42	Strongman mine	W	BBOP (2009)	Y	Y	N	Y	Y	N
43	Waikatea Station farm	L	Norton (2009)	Y	Y	N	N	N	Y
44	Waratah coal development	L	Martin *et al*. (2016)	Y	Y	Y	N	Y	Y
45	Tarrawonga open-cut mine	L	Martin *et al*. (2016)	Y	Y	Y	N	Y	N
46	A50 highway	L	Cuperus *et al*. (1999)	N	N	-	-	-	-
47	A73-South highway	L	Cuperus *et al*. (1999)	N	N	-	-	-	-
48	E12 highway	L	McGillivray (2012)	Y	Y	N	Y	N	Y
49	Mertainen mine	L	McGillivray (2012)	Y	Y	N	Y	N	Y
50	A20 motorway intersection Peene Valley	L	McGillivray (2012)	Y	Y	N	Y	N	Y
51	A20 motorway intersection of Trebel and Recknitz Valley	L	McGillivray (2012)	Y	N	-	-	-	-
52	Aircraft factory Mühlenberger Loch	L	McGillivray (2012)	N	N	-	-	-	-

Project name		Source		Development approved	Offset strategy	Information source			
						EIA		Offset strategy	
						1st	2nd	1st	2nd
53	Development Trupbach (Siegen), North Rhine-Westfalia	L	McGillivray (2012)	N	N	-	-	-	-
54	Colliery extension Haniel	L	McGillivray (2012)	N	N	-	-	-	-
55	Port expansion Rotterdam	L	McGillivray (2012)	N	N	-	-	-	-
56	Railway (Nordmaling to Umeå) Bothnia	L	McGillivray (2012)	N	N	-	-	-	-
57	Dam construction La Breña II, Andalucia	L	McGillivray (2012)	N	N	-	-	-	-
58	Rail development (Paris–Strasbourg) TGV East	L	McGillivray (2012)	N	N	-	-	-	-
59	Airport expansion Karlsruhe/Baden-Baden	L	McGillivray (2012)	N	N	-	-	-	-
60	Port construction Granadilla, Tenerife	L	McGillivray (2012)	N	N	-	-	-	-
61	Lübeck-Blankensee airport, Schleswig-Holstein	L	McGillivray (2012)	N	N	-	-	-	-
62	A20 motorway (Schleswig-Holstein)	L	McGillivray (2012)	Y	Y	N	Y	N	Y
63	A49 motorway extension (Hesse)	L	McGillivray (2012)	Y	Y	N	Y	N	Y
64	Infrastructure development Győr	L	McGillivray (2012)	N	N	-	-	-	-
65	Seine estuary	L	Meineri *et al*. (2015)	N	N	-	-	-	-
66	Great Keppel Island Resort	L	Meineri *et al*. (2015)	Y	Y	Y	Y	Y	Y
67	Notre-Dame-des-Landes airport	L	Meineri *et al*. (2015)	N	N	-	-	-	-
68	Röbäck, new bypass on route E12 west of Umeå	L	Persson *et al*. (2015)	N	N	-	-	-	-
69	Järfälla, expansion railway between Barkarby and Kallhäll	L	Persson *et al*. (2015)	N	N	-	-	-	-
70	Port of Antwerp	L	Schoukens and Cliquet (2016)	N	N	-	-	-	-

Notes: Projects were identified from two sources: websites (W) of conservation and industry organizations, and a literature (L) search on Web of Science. We coded projects with approved development and developed offset strategies. Documents used for coding were environmental impact assessments (EIAs) and offsetting strategies, which came from primary (1st; from development companies; eg EIAs) and secondary (2nd; published by third parties; eg scientific papers evaluating offsets) sources.

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WebTable 2. Data collected on development characteristics, impacts of development on biodiversity and ES, and offsetting characteristics

Variable		Description	ES n = 17	BD n = 24	Statistic	*P* value
Development characteristics						
1	Year*	Year development was approved			–1.1	0.27
2	Area (km^2)*	Area affected by development			0.26	0.79
3	Value (US$)*	Revenue over project life			0.02	0.84
4	Industry					
	Mining		0.47	0.33	0.32	0.57
	Infrastructure		0.12	0.17	$7e^{-32}$	1
	Gas		0.18	0.08	0.18	0.68
	Hydropower		0.18	0.13	0.01	0.99
	Other	Includes: wind, waste, urban	0.05	0.29	2.11	0.15
Impacts of development on BD and ES						
5	EIA	Environmental impact assessment conducted?	0.88	0.96	0.10	0.76
6	Consultation	Public consultation conducted?	0.82	0.88	$8e^{-32}$	1
7	BD offsite	BD impacts offsite?	0.24	0.38	0.37	0.54
8	BD type					
	Species	BD impacts a specific species?	0.76	0.83	0.02	0.88
	Habitat	BD impacts habitat(s)? Habitats were listed when specific species were said to be impacted by removal of habitat	0.88	0.92	$3e^{-31}$	1
	Ecosystems	BD impacts ecosystem(s)? Ecosystems were listed when specific species were not mentioned (eg tropical forests)	0.82	0.67	0.58	0.45
9	Impacted ES	Development impacts ES?	0.94	0.58	4.79	0.02
10	Residual ES	ES impacts remaining after mitigation hierarchy?	1.0	0.67	3.9	0.04
10	Offsite ES	ES impacts offsite?	0.75	0.50	1.08	0.30
11	Type ES	See WebTable 3 for definitions				
	Provisioning	ES impacts provisioning services?	0.75	0.93	0.67	0.41
	Regulating	ES impacts regulating services?	0.75	0.93	0.67	0.41
	Cultural	ES impacts cultural services?	0.88	0.86	$4e^{-31}$	1
12	Displace people	Development displaces people or livelihoods?	0.75	0.46	2.25	0.13

Offsetting characteristics						
13	Conservation org.	Involved conservation organization in offset design?	0.88	0.50	4.88	0.03
14	Displaced people	Offset displaces people or livelihood?	0.35	0.33	$7e^{-31}$	1
15	Approach					
	Conservation	Land-based protection	0.82	0.87	$1.1e^{-4}$	0.99
	Restoration	Land-based restoration	0.82	0.58	1.65	0.19
	Management	Non-land-based management (eg funded scientific research into threatened species)	0.53	0.67	0.32	0.57
16	BD requirement					
	Voluntary	BD offset not required by policy or finance	0.47	0.16	3.09	0.07^{+}
	Policy	BD offset required by government policy	0.47	0.66	0.87	0.35
	Finance	BD offset required for project finance	0.12	0.25	0.43	0.51
17	BD in-kind trade	Offsets same BD impacted by development?	0.65	0.83	0.85	0.36
18	Location					
	Onsite	Offset onsite (ie within development, Variable 2)	0.53	0.39	0.58	0.58
	Offsite	Offset offsite (ie outside development, Variable 2)	0.94	0.95	$2e^{-30}$	1
19	Area (km^2)*	Area of biodiversity offset			–0.31	0.75
20	Landscape plan	Offsets incorporated into landscape plan (eg protected area network, or strategic development plan)	0.41	0.74	1.97	0.08^{+}
21	ES type	See WebTable 2 for definitions				
	Provisioning	Offset provisioning services?	0.58			
	Regulating	Offset regulating services?	0.76			
	Cultural	Offset cultural services?	0.88			
22	ES requirement					
	Voluntary	ES not considered by policy or finance	0.64			
	Policy	ES considered due to government policy	0.35			
	Finance	ES considered for project finance	0.05			
23	ES in-kind trade	Offsets same ES impacted by development?	0.53			
24	Consider ES	Did offset consider ES? To qualify, it must be demonstrated that the offset was designed and implemented to achieve ES goals; this excludes those that simply mention potential ES co-benefits				

Notes: All variables were binary, unless otherwise indicated. Variables 1–23 are summarized (for binary variables only) and compared for Variable 24: ie offsets consider ES (n = 17) versus offsets focused exclusively on biodiversity (BD; n = 24). Statistics for binary variables are χ^2 and continuous variables are z scores. *Continuous variable; $^{+}P > 0.05$ but req $n < 35$ (see Methods).

WebTable 3. Ecosystem services, as defined by TEEB (2010).

Provisioning services	Regulating services	Cultural services
Provision of: food, fiber, fuel, fresh water, genetic resources, biochemical, natural medicines, pharmaceuticals, ornamental resources.	Regulation of: air quality, climate, water (ie timing and/or magnitude), human disease. Water purification or waste treatment; erosion control; biological control; crop pollination; storm protection.	Spiritual and religious values, cultural diversity; knowledge systems; educational values; inspiration; aesthetic value; social relations; sense of place; cultural heritage; recreation and ecotourism.

WebReference

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Biodiversity offsets may miss opportunities to mitigate impacts on ecosystem services

Laura J Sonter[1,2,3,4]*, Jesse Gourevitch[1,2], Insu Koh[1,2], Charles C Nicholson[1,2], Leif L Richardson[1,2], Aaron J Schwartz[1,2], Nitin K Singh[1,2], Keri B Watson[1,2], Martine Maron[3,4], and Taylor H Ricketts[1,2]

Biodiversity offsets are most commonly used to mitigate the adverse impacts of development on biodiversity, but some offsets are now also designed to support ecosystem services (ES) goals. Here, we assemble a global database of biodiversity offsets (*n* = 70) to show that 41% already take ES into consideration, with the objective of enhancing cultural, regulating, and provisioning services. We found that biodiversity offsets were more likely to consider ES when (1) development projects reported impacts on services, (2) offsets had voluntary biodiversity goals, and (3) conservation organizations were involved. However, offsets that considered ES were similar in design (eg offsetting approach, extent, and location) to offsets focused solely on biodiversity, suggesting that including ES goals may represent an attempt to strengthen community support for development projects, rather than to offset known ES impacts. We also found that 34% of all offsets displaced people and negatively affected livelihoods. Therefore, when biodiversity and ES are linked, current practices may not actually improve outcomes, instead incurring additional costs to communities and companies.

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Biodiversity offsets (hereafter "offsets") are used by both the public and private sectors to mitigate adverse impacts of development projects, such as mineral extraction and infrastructure construction (ten Kate and Crowe 2014). Offsets are conservation initiatives that aim to achieve no net loss of biodiversity by either increasing current levels of biodiversity or averting future biodiversity losses (Maron *et al.* 2012; Sonter *et al.* 2017). In principle, offsets should only be used to compensate for residual biodiversity losses (ie those that occur even after avoidance, minimization, and restoration efforts have taken place) and produce biodiversity gains that are in addition to those that might have occurred had no offsets been used. Furthermore, whatever biodiversity gains are achieved should be comparable to predicted residual losses (Bull *et al.* 2013; Gardner *et al.* 2013). However, available information about individual projects is limited and evidence of their success is scarce, leading many conservation scientists to question their practical effectiveness (Curran *et al.* 2014). Offsets have also been criticized for their narrow focus on species diversity (McKenney and Kiesecker 2010) and insufficient consideration of landscape context (Kiesecker *et al.* 2009), which is potentially to the detriment of ecosystem services (ES; Tallis *et al.* 2015).

Ecosystem services are the contributions that ecosystems make to human well-being (MA 2005). Given their link to biodiversity (Ricketts *et al.* 2016), ES are often incorporated into conservation activities (Goldman *et al.* 2008). Although biodiversity offset policies typically do not require ES considerations, there are two primary reasons why some policies or stand-alone projects may include ES. The first is to exploit synergies between biodiversity and ES; if development affects biodiversity and ES, offsets could be designed and implemented to jointly mitigate both impacts (Jacob *et al.* 2016; Schulp *et al.* 2016). Exploiting synergies can also provide additional benefits, even when development does not impact ES. Offsets can generate income through trading ES, such as carbon sequestration. Or it can strengthen community support for the project and thus the company's social license to operate. For example, the offset site may provide new opportunities for nature-based recreation. The second reason is to avoid negative trade-offs between offsets and ES, which may emerge if conservation activities restrict human access to ecosystems or displace nature-based livelihoods (Mandle *et al.* 2015; Kermagoret *et al.* 2016). Incorporating ES into offset policies for either of these reasons will benefit the human beneficiaries of ES as well as the companies responsible for offsetting: exploiting synergies is cost-effective and avoiding trade-offs reduces potentially expensive conflicts with local communities (Franks *et al.* 2014; Rainey *et al.* 2015).

Because of these mutual benefits, some biodiversity offsets do consider ES goals in their design and implementation (Madsen *et al.* 2010), as evidenced by emerging industry standards for environmental management (ICMM and IUCN 2013) and lending requirements of major financial institutions to mitigate impacts on biodiversity and ES (IFC 2012). However, despite anecdotal evidence, the proportion of offsets worldwide that consider ES is currently unknown; it is also unclear how

[1]*Gund Institute for Environment, University of Vermont, Burlington, VT;* [2]*Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT;* [3]*School of Earth and Environmental Sciences, The University of Queensland, Brisbane, Australia;* [4]*Centre for Biodiversity & Conservation Science, The University of Queensland, Brisbane, Australia* *(*l.sonter@uq.edu.au*)

offsets differ when ES are taken into account. These knowledge gaps are not surprising, given the limited information on offsets and the fact that evaluations are rarely performed at the project level (McKenney and Kiesecker 2010), especially for ES outcomes (Jacob *et al.* 2016; Schulp *et al.* 2016). Addressing these gaps will reveal current practices, identify what motivates companies to consider ES, and provide the insight needed for the public and private sectors to improve offsetting outcomes. Such knowledge is critical, given that offsets are increasingly popular mitigation tools used to address declining levels of biodiversity worldwide (ten Kate and Crowe 2014).

We assembled a global database of biodiversity offsetting projects and used it to answer two questions: (1) what proportion of offsets currently considers ES and (2) how do these offsets differ from those focused exclusively on biodiversity goals? Specifically, we quantified differences in: (a) development characteristics, such as size, value, duration, and industry; (b) impacts of development on biodiversity and ES, including impact type and location, and assessment methods; and (c) offsetting characteristics, such as their requirements (policy, financing), design (size, siting, biodiversity goals), and consequences for people.

Methods

Project database

We identified biodiversity offsetting projects (ie the offset and its associated development) from multiple sources (WebTable 1). In September 2016, we searched Web of Science for "biodiversity offset" OR "(biodiversity or biological) AND compensation AND mitigation" by topic (230 papers, 47 projects identified). We also searched the websites of organizations known to work on offsetting (four organizations, 23 additional projects identified). We focused on biodiversity offsets rather than ES mitigation efforts generally, and did not include online offsetting repositories in our search because the few that exist either are limited to specific policy contexts or do not contain the information needed for our analysis (see "Data collection" section). Due to our unavoidably small sample size, results should be interpreted with caution.

Data collection

We collected data on each project in three steps. First, we determined if development had regulatory approval and whether an offsetting strategy was available; projects without either were excluded from further analysis. Second, we collated documents describing projects, recording whether they were primary information sources (from development companies; eg environmental impact assessments) or secondary (published by third parties; eg scientific papers evaluating offsets). Third, from these documents, we extracted information on 24 variables related to development characteristics, impacts of development on biodiversity and ES, and offsetting characteristics (WebTable 2). One variable assessed whether offsets considered ES in their design and implementation. WebTable 2 defines "considered ES" and WebTable 3 lists potential ES. Each project was independently assessed by two authors. Inter-rater accuracy (between authors) was >70% for binary variables, and scores for continuous variables were correlated ($r > 0.8$). All discrepancies between authors were discussed until consensus was reached prior to data analysis.

Data analysis

We compared offsets that considered ES with offsets focused exclusively on biodiversity goals for all measured variables (WebTable 2). Proportion tests were used for binary variables and logistic regressions for continuous variables. Given the limited sample size, we also performed power analyses for each test to determine the sample size required ("req n") to detect significant differences ($\alpha = 0.05$, $\beta = 0.8$). When $P > 0.05$ but req $n < 35$, we reported this result to indicate potential differences in variables limited by sample size. Analyses were performed in R 3.4.0 (R Core Team 2014).

Limitations

Results reflect the contents of collated documents. Although all projects presented some information on environmental impacts and offsetting strategies, some projects had more information than others, and some documents may have been biased to reflect author purposes (eg to better ensure project approval). As a result, our results may not reflect actual outcomes of offsetting, but instead the aspirations of companies. However, the document's information source (ie primary versus secondary) was not significantly related to the proportion of offsets that considered ES suggesting that this did not bias our results. Our final project database is available online (WebTable 1; doi.org/10.6084/m9.figshare.5616160).

Results

We identified 70 biodiversity offsets, and found sufficient information to include 41 in our analysis (Figure 1a; WebTable 1). Of the 41 offsets, 17 (41%) considered ES; of these, 65% did so voluntarily, 35% were required by policy, and 5% did so for reasons relating to project finance (Figure 1b; values exceeded 100% because one project considered one type of ES due to policy and other types voluntarily). In addition, of the offsets that considered ES, 88%, 76%, and 59% targeted cultural services (eg opportunities for nature-based recreation), regulating services (eg sediment retention), and provisioning services (eg food production), respectively (Figure 1c). Across all projects, 53% made in-kind ES trades (ie the ES considered in the offset was the same type as that impacted by the development project; WebFigure 1).

Development characteristics

Development projects included in the analysis spanned 22 countries (Figure 1a) and multiple industries (WebFigure 2), and ranged widely in duration (2–41 years), reported value (US\$17 million–85 billion), and size (0.6–5700 km^2). None of these characteristics differed significantly between offsets that considered ES and those focused exclusively on biodiversity (WebTable 2).

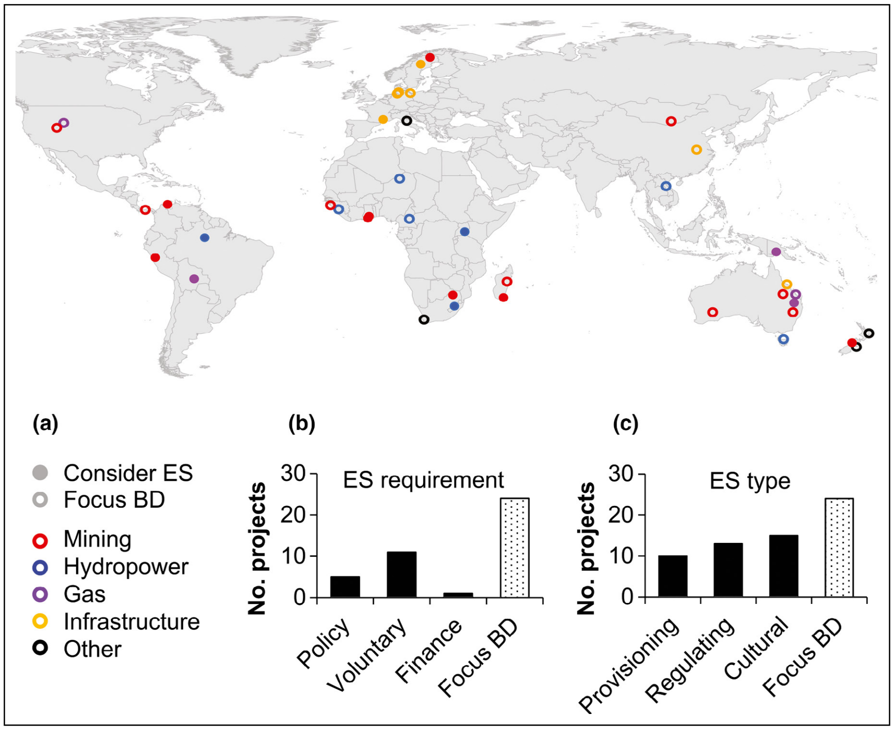

Figure 1. *(a) Map of biodiversity offsetting projects (*n *= 41). Closed circles indicate offsets that consider ES, whereas open circles show offsets that focus exclusively on biodiversity (BD). Circle color indicates the project's industry sector; "Other" includes development for wind, waste, and urban projects. See WebFigure 2 for comparison of industries between offsets that consider ES and those focused exclusively on BD. (b) Requirements for offsets (*n *= 41) to consider ES: 14% were required by policy, 27% were voluntary, 2% were for project finance, and 59% were focused exclusively on BD (values exceeded 100% because one project considered one type of ES due to policy and other types of ES voluntarily). (c) Number of offset projects that focused exclusively on biodiversity (*n *= 24) versus those that considered any of the three types of ES: provisioning, regulating, or cultural services (see WebTable 3 for example services within each type). Note: some offsets considered more than one type of ES, so the sum of columns >100% (ie >24 projects).*

Impacts of development on biodiversity and ES

Environmental impact assessments and public consultations were conducted for 88% and 83% of projects, respectively. Biodiversity impacts were reported onsite for all projects and offsite for 31% of projects; impacts on species, habitats, and ecosystems were reported for 80%, 90%, and 73% of projects, respectively. None of these proportions differed between offsets that considered ES and offsets focused exclusively on biodiversity (WebTable 2).

Adverse impacts of development on ES were reported for 73% of projects. All of these projects reported onsite impacts and 63% also reported offsite impacts, while 83% focused on provisioning services, 83% on regulating services, and 86% on cultural services. The proportion of projects reporting ES impacts was significantly greater for offsets that considered ES than offsets focused exclusively on biodiversity ($\chi^2 = 4.79$, $P = 0.02$; Figure 2). No significant differences in proportions were found for impact location or ES type (WebTable 2).

Fifty-six percent of development projects reportedly displaced people and negatively affected livelihoods, a proportion that did not differ significantly between offsets that considered ES and those focused exclusively on biodiversity.

Offsetting characteristics

Some offsets were voluntary (34%), whereas others were required by policy (51%) or for project finance (23%). The "voluntary" proportion was greater for offsets that considered ES than those focused exclusively on biodiversity ($\chi^2 = 3.09$, $P = 0.07$, req $n = 34$; Figure 2). Offsets that considered ES also had a significantly greater proportion involving conservation organizations ($\chi^2 = 4.88$, $P = 0.03$; Figure 2), but were incorporated into landscape plans less often ($\chi^2 = 3.12$, $P = 0.08$, req $n = 34$).

Different offsetting approaches were used to create biodiversity gains (85% used protection, such as establishing new protected areas; 68% used restoration, eg creating new habitat for threatened species; and 61% undertook non-land-based management, such as funding scientific research; WebFigure 3), and 95% of offsets used more than one approach. Offsets also varied in size (1–9400 km^2), location (43% onsite, 92% offsite), and biodiversity trades (73% were in-kind). None of these proportions differed significantly between offsets that considered ES and offsets focused exclusively on biodiversity (WebTable 2).

Thirty-four percent of offsets reportedly displaced people and negatively affected livelihoods, a proportion

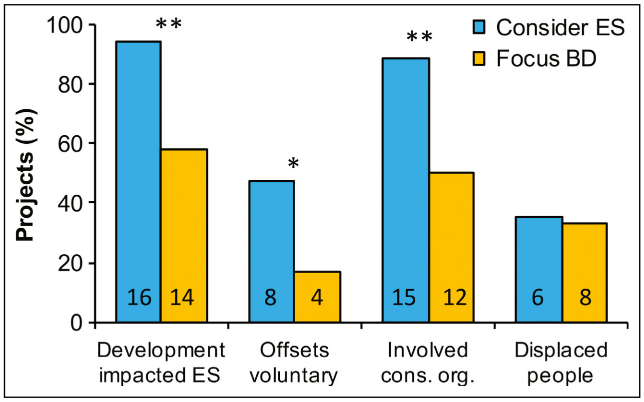

Figure 2. *Four key comparisons between offsets that considered ES (n = 17) and those focused exclusively on biodiversity (BD) (n = 24). Left to right: development impacted ES (WebTable 2, Variable 9); offsets were voluntary (WebTable 2, Variable 16); involved conservation organization (WebTable 2, Variable 13); and offsets displaced people or livelihoods (WebTable 2, Variable 14). Numbers inside columns indicate the number of projects; asterisks denote significant differences in proportions of projects that considered ES and those focused on BD (**P < 0.05; *P = 0.07).*

that did not differ significantly between offsets that considered ES and those focused exclusively on biodiversity (Figure 2).

Discussion

Forty-one percent of offsets considered ES in their design and implementation (Figure 1), highlighting the perceived importance of ES to companies responsible for offsetting. We found that four of the 23 variables differed between offsets that considered ES and those focused exclusively on biodiversity: whether (1) development reported impacts on ES, (2) biodiversity offsets were voluntary, (3) conservation organizations were involved, and (4) offsets were incorporated into landscape plans (Figure 2). However, offsets that considered ES were similar in design (eg approach, size, location) to those focused on biodiversity, suggesting that including ES was probably not intended as an effort to jointly mitigate biodiversity and ES impacts.

Differences between offsets that do and do not consider ES

When linked to development that reported impacts on ES, offsets considered ES more often. Ninety-four percent of offsets that considered ES were linked to such development, compared to only 58% of the offsets focused exclusively on biodiversity (Figure 2). This suggests that companies may perceive synergies between biodiversity and ES and be motivated to jointly offset impacts on both to reduce total mitigation costs (Rainey *et al.* 2015). However, our database does not allow assessment of causation. We collected data largely from company reports, and companies that do not assess impacts on ES may be less likely to reference ES in their offsetting strategies. Independent project evaluation is needed (see "Conclusions" section); however, the 42% of offsets that were linked to development that reported impacts on ES but only focused on biodiversity may miss opportunities to mitigate impacts on both when biodiversity and ES are linked.

Three other variables increased the likelihood that offsets would consider ES. (1) Third-party stakeholders may play a role, as offsets that considered ES were significantly more likely to involve conservation organizations than offsets focused on biodiversity (Figure 2). Such involvement included providing assistance to offsetting proponents in the application of conservation planning tools (eg The Nature Conservancy's Development by Design methodology; Kiesecker *et al.* 2009), and may reflect the increasing interest these organizations have in jointly conserving biodiversity and ES. (2) Biodiversity offsets that considered ES were also 2.7 times as likely to be voluntary (ie not required by policy or for project finance purposes; Figure 2), and therefore possibly had greater flexibility in their biodiversity offsetting goals and targets. (3) Offsets that considered ES were half as likely to be incorporated into government-mandated landscape plans, suggesting that companies operating beyond legal compliance see value in considering ES – perhaps to generate income through ES trades or to improve their social license to operate.

Similarities between offsets that do and do not consider ES

Offsets that considered ES were similar to offsets focused on biodiversity with respect to the remaining 19 tested variables (WebTable 2), two of which were unexpected. First, we anticipated that negative effects on people would occur less frequently among offsets that considered ES – that is, that these conservation activities would not restrict access to land and other natural resources (Sonter *et al.* 2014) – but we found no significant differences in whether offsets reportedly displaced people and negatively affected livelihoods (Figure 2). This is a cause for concern, given that 35% of all offsets did so, often reducing provisioning services (eg food production) to affect local people, some of whom were indigenous. These consequences ranged from relatively minor restrictions (eg one farmer losing part of their property) to large-scale community resettlements. Moreover, 35% may be a conservative estimate, given that many offsets may displace people and livelihoods but exclude this information from offsetting strategies or impact assessments (eg the Anglo American Platinum mine in South Africa). Although conserving threatened areas will maximize biodiversity gains by averting losses (Sonter *et al.* 2014), the resulting trade-offs between biodiversity and productive land uses may incur large costs to communities if not mitigated through additional means, such as financial compensation (Franks *et al.* 2014; Mandle *et al.* 2015; Figure 3).

We also expected that the design of offsets that considered ES would be distinct from that of offsets focused solely on biodiversity, as is the case when ES are integrated into other forms of conservation (Goldman *et al.* 2008). Yet we found no differences in approach (WebFigure 3), size, location, or biodiversity trades (ie in-kind versus out-of-kind) between the two types of offsets (WebTable 2). This may suggest that ES are relatively simple to include in offsets, although this hypothesis is debatable – trade-offs with biodiversity goals often occur (Mandle *et al.* 2015). Alternatively, design similarities may indicate that ES are considered secondarily (rather than in parallel) to biodiversity goals – enhancing services otherwise unaffected by development and not beyond what would have occurred if offsets had focused only on biodiversity goals. Indeed, 47% of offsets that considered ES made out-of-kind trades (ie enhancing services not impacted by development) and all offsets making in-kind ES trades targeted cultural services (often recreation) by permitting people to access the offset site (WebFigure 1). Including ES in an offset may be motivated more by a company's desire to strengthen their social license to operate than their desire to mitigate their impact on ES.

Policy implications

Many companies recognize the value of considering ES in offsets, but our results suggest that this consideration is not a strategic effort to optimize outcomes for both biodiversity and ES. One opportunity to improve current practice and enhance outcomes is through policy interventions, including changes to current offsetting regulations to allow companies to exploit synergies and avoid trade-offs. This approach may be particularly effective given that policies triggered 51% of all biodiversity offsets, but only required 14% to consider ES (Figure 1b). Policy changes should be context-dependent, and when interventions are impractical, understanding factors inhibiting consideration of ES will be key to improving outcomes.

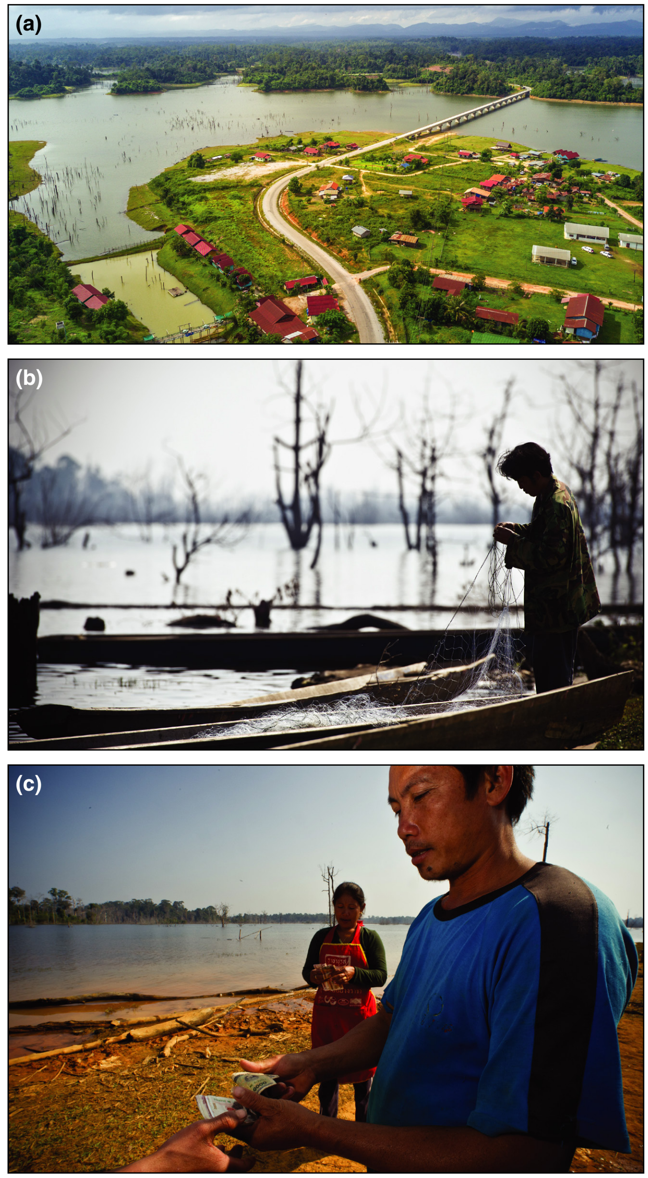

Figure 3. *(a) Nam Theun 2 Hydroelectric Project, Lao PDR (WebTable 1, Project 32). Development project and associated infrastructure (a) negatively impacted ES, displaced local people and their nature-based livelihoods, and undertook biodiversity offsetting. However, in this project, the offset did not consider ES in its design and implementation but rather compensated impacted communities through other means, such as (b) livelihood training in alternative fishing methods and locations and (c) financial transactions.*

Conclusions

As mentioned above, only 14% of the offsets investigated here were required to consider ES by policy. Companies nonetheless explicitly considered ES in the design of their biodiversity offsets for at least two additional reasons: (1) to exploit potential synergies and (2) to reduce adverse trade-offs. Although 41% of offsets considered ES, they did not necessarily gain the full suite of benefits from doing so; some failed to jointly mitigate impacts of development and offsets on ES, others caused additional harm to people. Systematically considering ES in offsets may help to improve outcomes, but offsets should be optimized so as to avoid undermining the achievement of no net loss of biodiversity.

Quantifying offsetting outcomes is an important next step that requires progress on three fronts. (1) Projects must be evaluated. Our study is one of the first to assess offsets at the project level; most other research has focused solely on policies (eg McKenney and Kiesecker 2010). However, we obtained much of our data from company documents, which may be biased. Project evaluation combining in-situ fieldwork, quasi-experiments, and scenario modeling, is needed. (2) Project data must be acquired and made publicly available. Offsetting registries are needed to promote transparency and accountability, and their current scarcity limits project evaluation across diverse policy contexts. (3) The effects of offsets on biodiversity and ES must be quantified. This is difficult for many reasons, one being the issue of determining what would have happened to ES if development had not been approved and offsets had not been implemented.

As biodiversity offsetting becomes an increasingly common mitigation tool, it is crucial that ES synergies be exploited, and trade-offs avoided, wherever possible.

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Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.1781/suppinfo

