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Stakeholder priorities determine the impact of an alien tree invasion on ecosystem multifunctionality

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Abstract

1. While the ecological impact of environmental change drivers, such as alien plant invasions, is relatively well described, quantitative social-ecological studies detailing how these changes impact multiple ecosystem services, and subsequently stakeholders, are lacking.
2. We used a social-ecological approach to assess how *Prosopis juliflora* (Prosopis henceforth), an invasive tree, affects the provision of multiple ecosystem services to different stakeholder groups in a degraded East African dryland. We combined plot-based ecological data on the impacts of the tree on indicators of ecosystem service supply with questionnaire survey data describing ecosystem service priorities from eight different stakeholder groups. These data were then used to quantify how tree invasion impacted individual ecosystem services, and the overall supply of services, relative to the priorities of each stakeholder group, using an ecosystem service multifunctionality metric.
3. In the study area, we found that Prosopis significantly increased the supply of shade, wood production and honey production, but reduced the supply of water availability, tourism potential and biodiversity protection.
4. Priorities for specific services differed between stakeholder groups. Although most groups assigned a high priority to provisioning services, such as water and crop production, it was either provisioning or cultural services which were a primary source of income, that were deemed most important.
5. Combining supply and priority data showed that most stakeholder groups saw a net decrease in ecosystem service multifunctionality with increasing Prosopis invasion, or no significant change overall. Increasing Prosopis cover increased multifunctionality for only two stakeholder groups, charcoal producers and NGOs involved in regional development.

6. Our research highlights the need to account for stakeholder priorities in studies of how global change impacts ecosystem multifunctionality. We found that there are conflicting patterns of ecosystem service priority between different stakeholder groups, resulting in large variation in how different groups were impacted by the invasive tree. Our approach also highlights possible synergies and conflicts when managing this tree invasion. More broadly, we recommend that future studies of ecosystem multifunctionality explicitly consider differing stakeholder priorities, as these strongly influence the perceived impact of environmental and land management change.

KEYWORDS

alien species, drylands, ecosystem services, invasive species, multifunctionality, priorities, Prosopis, supply and demand

1 | INTRODUCTION

Global environmental change is driving land cover changes across the globe, resulting in changes to the supply of many ecosystem services, including food production, biodiversity conservation, carbon storage and cultural benefits (Allan et al., 2015; Cardinale et al., 2012; IPBES, 2018). Whereas some drivers of environmental change, such as point source pollution, have a clear negative impact (Defries & Nagendra, 2017), other drivers have been described as a wicked problem (Woodford et al., 2016) in that they have both positive and negative impacts on ecosystem services and the stakeholders who use them. This is because a driver can increase some services while decreasing others, and because different stakeholders prioritize different ecosystem services (priority; see glossary in box 1), desire different levels of their supply (demand). As a result, conflicts can emerge when it comes to identifying and applying land management options (Defries & Nagendra, 2017). The ecological impacts of global change drivers, for example, on ecosystem functioning and the potential supply of ecosystem services, have been well described (Allan et al., 2015; Grace et al., 2016; Isbell et al., 2013). However, a detailed and quantitative understanding of how changes in supply caused by global environmental change affect different stakeholder groups is absent, despite this being a cause of land use conflicts. Identifying which services stakeholders prioritize (Plieninger et al., 2013; Washbourne et al., 2020) and potential synergies and trade-offs between different stakeholder groups (Hicks et al., 2013; Torralba et al., 2018) is thus crucial if we are to identify land management strategies that promote the sustainable use of multiple ecosystem services.

One suggested way of measuring how environmental change affects the supply of multiple services and in turn, multiple stakeholder groups is the ecosystem service multifunctionality approach (Manning et al., 2018). Here, ecosystem service multifunctionality is defined as the simultaneous supply of all ecosystem services of interest, relative to their human demand, where demand is defined as the level of service provision desired by people (Maron et al., 2017). The ecosystem service multifunctionality approach builds upon the multifunctionality metrics used in the biodiversity–ecosystem functioning field (Allan et al., 2015; Barnes et al., 2017; Byrnes et al., 2014), but advances these by combining ecological data describing the supply of multiple ecosystem services with social data quantifying the relative priority of each service. The approach also advances on existing methods in ecosystem service research such as the identification and mapping of supply bundles or demand (Frei et al., 2018; Raymond et al., 2009). In addition to the measures of trade-offs and synergies that these existing methods provide, ecosystem service multifunctionality summarizes the overall benefit provided by an

BOX 1 Glossary

Ecosystem service multifunctionality: Simultaneous supply of multiple prioritized ecosystem services, relative to their human demand (adapted from Manning et al., 2018).

Priority: The relative importance of an ecosystem service to a stakeholder (based on Chan et al., 2012). All prioritized services can be considered demanded to at least some level.

Demand: 'The amount of a service required or desired by society' (Villamagna et al., 2013).

Benefit: The benefit stakeholders receive from an ecosystem service. This can be material or non-material depending on the service. In *ecosystem service multifunctionality* scores it is standardized as a value ranging between zero (lowest level across the possible or observed supply gradient) and one (highest level across the possible or observed supply gradient), and weighted by its priority.

Supply–benefit relationships: A relationship describing the benefit received by stakeholders for any given level of ecosystem service supply (Manning et al., 2018). Supply is scaled between zero (minimum possible of observed supply) and one (maximum possible of observed supply) in ecosystem service multifunctionality scores.

ecosystem, potentially for multiple stakeholder groups or whole communities. This holistic measure is possible as it includes all ecosystem services prioritized by stakeholders, and thus provides a more complete measure of overall ecosystem service provision than many ecosystem service studies, which typically present a subset of the full portfolio of services (Hölting et al., 2019). The metric can also be linked to drivers of ecosystem service change, as we do here, to quantitatively assess the overall impact of a global change driver on ecosystem service provision. Finally, because the importance of all major services is accounted for the net balance of impacts (e.g. where positive and negative changes trade-off) can be calculated.

To date, stakeholder inclusion in multifunctionality research has been rare (Hölting et al., 2019) and has mostly focused on either qualitative assessments of the ecosystem services people are aware of or consider important (Bernués et al., 2015; Darvill & Lindo, 2016; Washbourne et al., 2020; Zoderer et al., 2019), or participatory mapping that assesses where services are valued or used within the landscape (Klain & Chan, 2012; Plieninger et al., 2013). However, these approaches are unable to show how different stakeholders are affected by environmental change as they do not fully incorporate the drivers of ecosystem service supply. Consequently, these approaches cannot identify how environmental drivers influence mismatches between the supply and demand of multiple ecosystem services (Wei et al., 2017). Most studies where ecosystem service supply data have been integrated with stakeholder data have relied on coarse and large-scale measures of supply, such as those gathered from expert opinion (Darvill & Lindo, 2015), presence–absence maps of services (Gos & Lavorel, 2012; Martín-López et al., 2014) or only a selection of services (e.g. Lavorel et al., 2011). Our ecosystem service multifunctionality approach can overcome some of these shortcomings, as it combines ecosystem service supply data, based on primary data, with ecosystem service priority data on the relative importance of each ecosystem service to stakeholders (Manning et al., 2018).

Here, we make a first attempt at operationalizing the ecosystem service multifunctionality approach, which has received significant attention, but has not yet been used with real data for both the supply and priority elements. We use the impacts of an invasive tree species on multiple stakeholder groups in a degraded Kenyan dryland system as an example. *Prosopis juliflora* (Sw.) DC. (Prosopis henceforth; Figure 1) is a small tree/large shrub that is native to Central and South America, but has been introduced to drylands worldwide (Pasiecznik et al., 2001). Prosopis was widely introduced to Kenya in 1986 to reduce soil erosion and improve rural livelihoods by providing income through wood (Mwangi & Swallow, 2005). However, Prosopis quickly escaped from the original plantations and has spread rapidly across many land use types, including croplands and grasslands (Mbaabu et al., 2019). The invasion of Prosopis causes trade-offs in ecosystem service supply as it increases income from wood and charcoal (Linders et al., 2020) but can also increase the incidence of human diseases, such as malaria (Muller et al., 2017), and decrease biodiversity, fodder production and soil carbon stocks (Linders et al., 2019). The perception of Prosopis by rural people in Kenya is mixed, with most people agreeing that Prosopis has both positive and negative impacts but

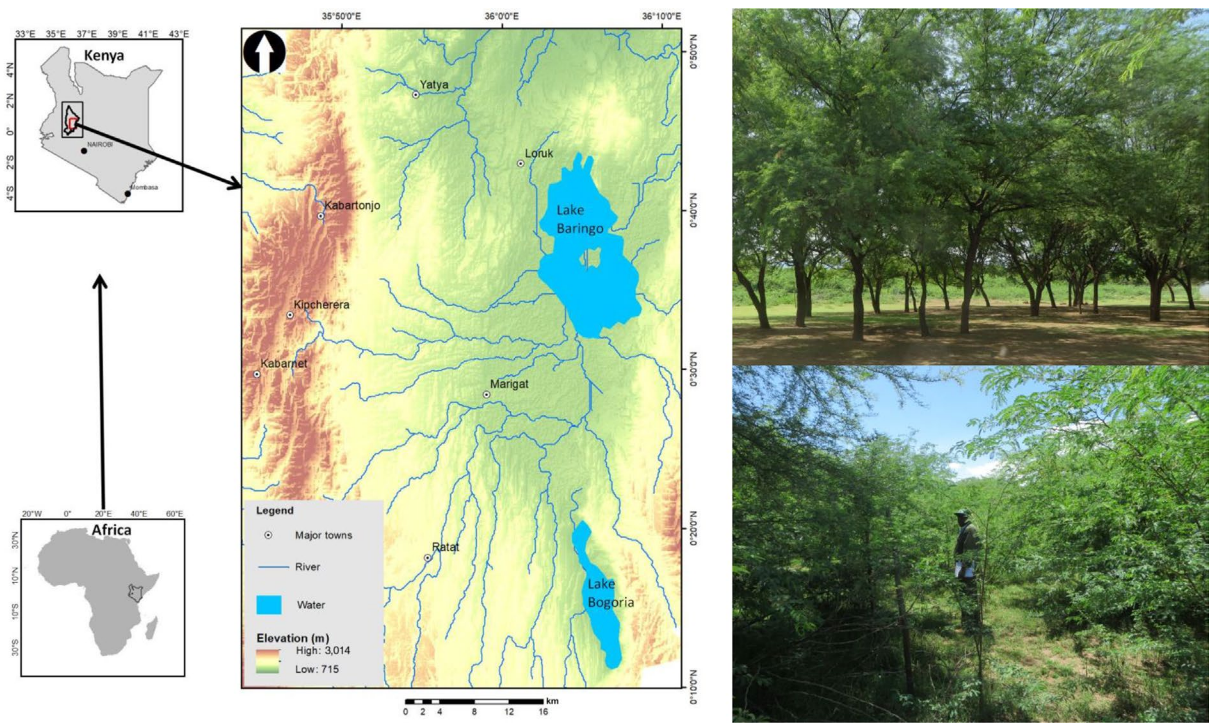

FIGURE 1 Location of the study area within Kenya (left) and pictures of Prosopis, the study species, showing a Prosopis plantation (top right) and a recently invaded area (bottom right)

that overall the negative impacts outweigh the positive effects (Bekele et al., 2018). Although the ecological impacts of Prosopis on individual ecosystem properties and services are well described, less is known about how these ecological changes affect the supply of multiple ecosystem services to local communities and how invasion impacts different stakeholder groups. As most rural Africans directly depend on multiple provisioning services for a large part of their income (Reynolds et al., 2020), we can expect differences in priorities between stakeholders based on different sources of income, for example, crop farmers and pastoralists. However, it is unknown which other ecosystem services are valued apart from those that provide direct income, and how important these are to stakeholders. Therefore, identifying the ecosystem service priorities of different stakeholder groups is crucial for the development of a strategy for Prosopis management that is acceptable to most stakeholder groups.

In this study, data we first assessed how Prosopis affected the supply of multiple ecosystem services using plot-scale ecological data. Second, we assessed the relative priorities for different ecosystem services across a wide range of stakeholder groups, by performing questionnaire surveys. We then analysed how ecosystem service multifunctionality was affected by Prosopis for each stakeholder group by integrating the ecological supply data with data on the ecosystem service priorities of stakeholders.

2 | METHODS

2.1 | Study area

Data were collected in Baringo County, Kenya, a semi-arid area located in the Great Rift Valley, as part of the larger Woody Weeds project (e.g. Eckert et al., 2020; Linders et al., 2019; Mbaabu et al., 2019). Baringo has a long history of Prosopis invasion and a wide variety of land uses (Mbaabu et al., 2019) and stakeholder groups, making this area especially suited for our study. Ecological and stakeholder data in Baringo were collected around Lake Baringo and Lake Bogoria (Figure 1; between latitude 0°15′ and 0°36′North and between longitude 35°58′ and 36°08′East). In this area, a full gradient of Prosopis invasion is present, with cover ranging from 0% to 100%. Additionally, stakeholder data were collected on the western shores of Lake Baringo, an area which currently displays low levels of invasion, and in the Baringo County government in Kabarnet, the County's capital. The Baringo lowlands are characterized by a semi-arid climate (mean annual temperature of 24.6°C and mean annual precipitation of 635 mm (Kassilly, 2002). Historically, Baringo was dominated by grasslands. However, the region has a long history of high human disturbance and is currently sparsely vegetated and dominated by shrubs and small trees (Mbaabu et al., 2019). Currently, livestock, crop production and charcoal making are the main sources of income for most residents. The ecological data used here were collected in highly degraded areas, which are typical of most of the study area, and Prosopis invaded land in Kenya. Ecosystem service supply at low Prosopis cover levels is thus likely to be unrepresentative of other, less degraded, areas. Accordingly, the gradient presented here should be viewed as running from degraded and uninvaded to degraded and invaded, and not indicative of Prosopis impacts upon more pristine landscapes.

2.2 | Multifunctionality approach

The approach to measuring multifunctionality used here is derived from metrics devised to measure how biodiversity influences ecosystem multifunctionality (Allan et al. 2015; Hector & Bagchi, 2007; Maestre et al., 2012), but advances these by incorporating measures of stakeholder priorities, and the benefit received per unit of supply. Traditionally, the quantification of multifunctionality has mostly used either an averaging approach, where multifunctionality is the mean value of all services (Hooper & Vitousek, 1998), or a threshold approach (Byrnes et al., 2014), in which services are weighted equally and are considered to be delivered, and thus demand fully met, if they pass an arbitrary threshold, typically a percentage of the maximum observed value (Gamfeldt et al., 2008). In contrast, ecosystem service multifunctionality measures combine ecological data describing the supply of multiple ecosystem services with social data, using stakeholder data to quantify the relative priorities for each service. To measure and calculate ecosystem service multifunctionality, the following steps are taken (see Figure 2). First, stakeholders assign priority scores to a complete list of locally supplied services (Figure 2; panel 1). Next, the supply of all services prioritized by stakeholders is measured (Figure 2; panel 2) and then each is converted to a benefit measure using a 'supply–benefit relationship' that defines the benefit received per unit of supply (Figure 2; panel 3). These benefit scores are then standardized to a 0–1 range, where 1 is the maximum possible benefit, and multiplied by the relative priority of each service. As the priority scores also sum to one, the result is a multifunctionality score in ranging from 0 to 1 (Figure 2; panel 4).

While demand is a dynamic property, it is represented as a fixed value in ecosystem service multifunctionality measures. In these, the service level demanded is represented by two separate components. The first of these is the priority score, in that any service with a priority score of zero is not demanded at all. The second component is the supply–benefit relationship. This can take a variety of forms and describes the relationship between ecosystem service supply and the benefit received. Benefit scores in this relationship range from 0 to 1, with zero representing no benefit and 1 being the maximum that is biophysically possible, or observed. For services in which the benefit accumulates linearly with supply, this is a simple linear relationship (Figure 3; panel 3 left graph). However, the saturation of demand can be represented by an asymptotic relationship, as can the failure for benefits to be realized at low levels of supply, with an exponential or 'threshold plus' form when above a certain supply level there are no extra benefits (Figure 3; panel 3 right graph; Manning et al. 2018). The quantification of supply–benefit relationships

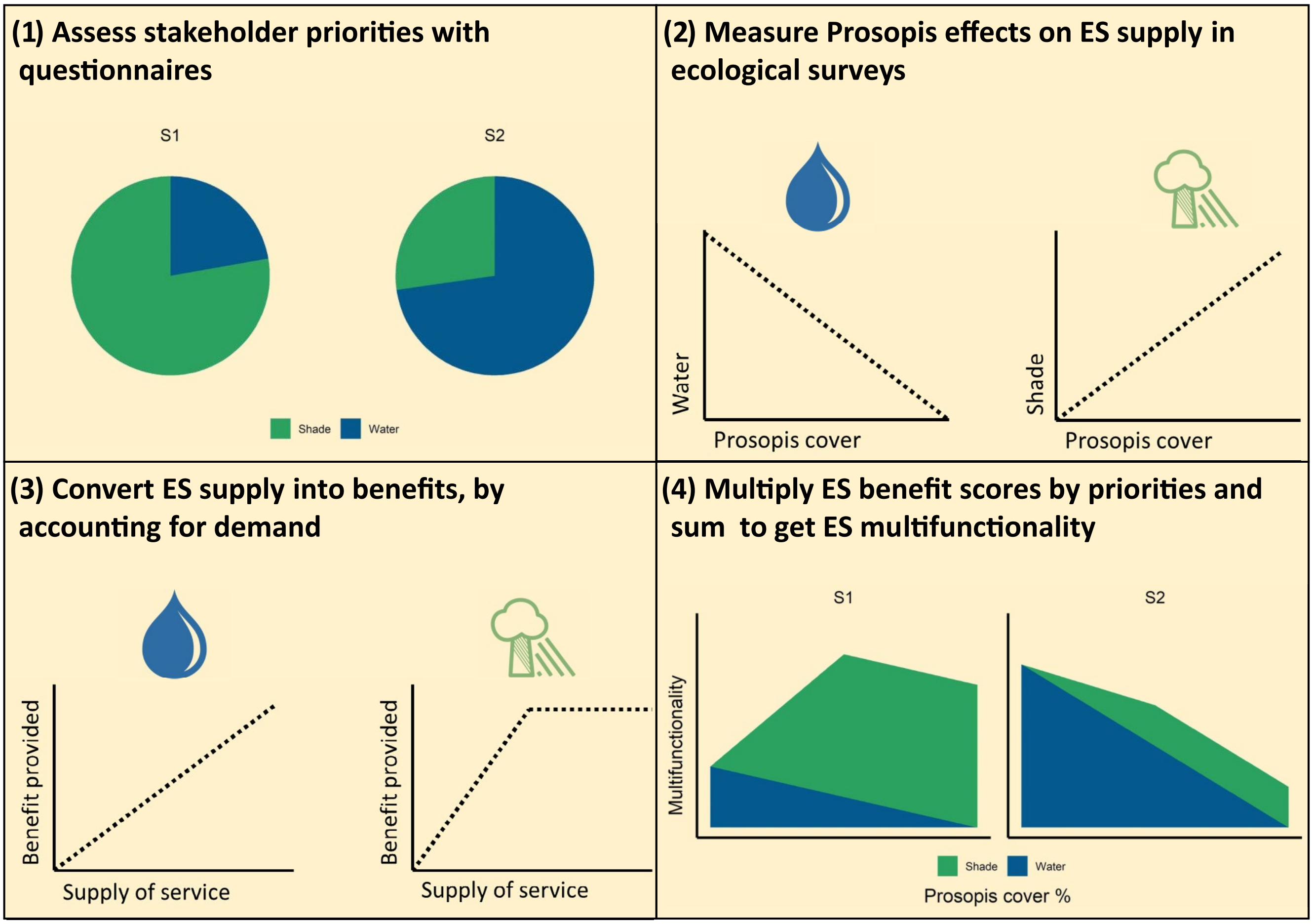

FIGURE 2 Steps taken in the ecosystem service multifunctionality quantification, using two hypothetical stakeholder groups (orange and grey) and two ecosystem services (shade and water). Priorities are assessed by asking stakeholders to allocate a fixed number of points across a complete list of ecosystem services. The conversion of supply measures into benefit is performed via a supply–benefit relationship, which can assume a number of forms, depending on whether benefits are present at low supply or saturate at high supply where demand is fully met (see Section 2 for details)

ideally requires extensive data in its own right (e.g. additional social surveys or economic analysis). However, in the absence of this information, this relationship can be assumed, and its sensitivity to other forms was tested. See Manning et al. (2018) for a tutorial describing the approach in detail.

2.3 | Data collection

2.3.1 | Stakeholder data

Data on the ecosystem service priorities of different stakeholders were gathered via individual face-to-face interviews, conducted in August 2019. To ensure that our research was conducted ethically, we took the following steps: (a) All interviewees were informed about the purposes of the study and gave their informed consent orally before the start of each interview, as a proportion of the interviewees was illiterate, this was not done in written form. Interviewees were also given the option to halt the interview at any time. (b) Data were treated anonymously and are presented in the article in a way in which individual participants cannot be identified. (c) Data files shared in Dryad are anonymized by removing affiliations and locations. The Senckenberg BIK-F Institute, by whose employees the research was led, does not have an ethics committee for social science work. In total, 234 questionnaires were successfully completed, spread across eight stakeholder groups, each with their own interests in land management and income source. Relevant stakeholder groups were pre-defined based on discussions with local inhabitants and scientists familiar with the region, and represented the main land users and managers of the region. These groups were as follows: conservationists, tourism industry, crop farmers, pastoralists, government officials, developmental NGO employees, charcoal producers and teachers, see Table 1 for affiliations and distinguishing characteristics of these groups. Stakeholder sampling was done in two different ways: by visiting villagers in their homes and by visiting institutions. Villages were selected throughout the study region, to cover all accessible areas (limited by road conditions and tribal conflicts) and included all areas where ecological sampling was done. In total, 60 villages were visited and in each village 2–10 interviews were conducted based on the presence of stakeholders in their

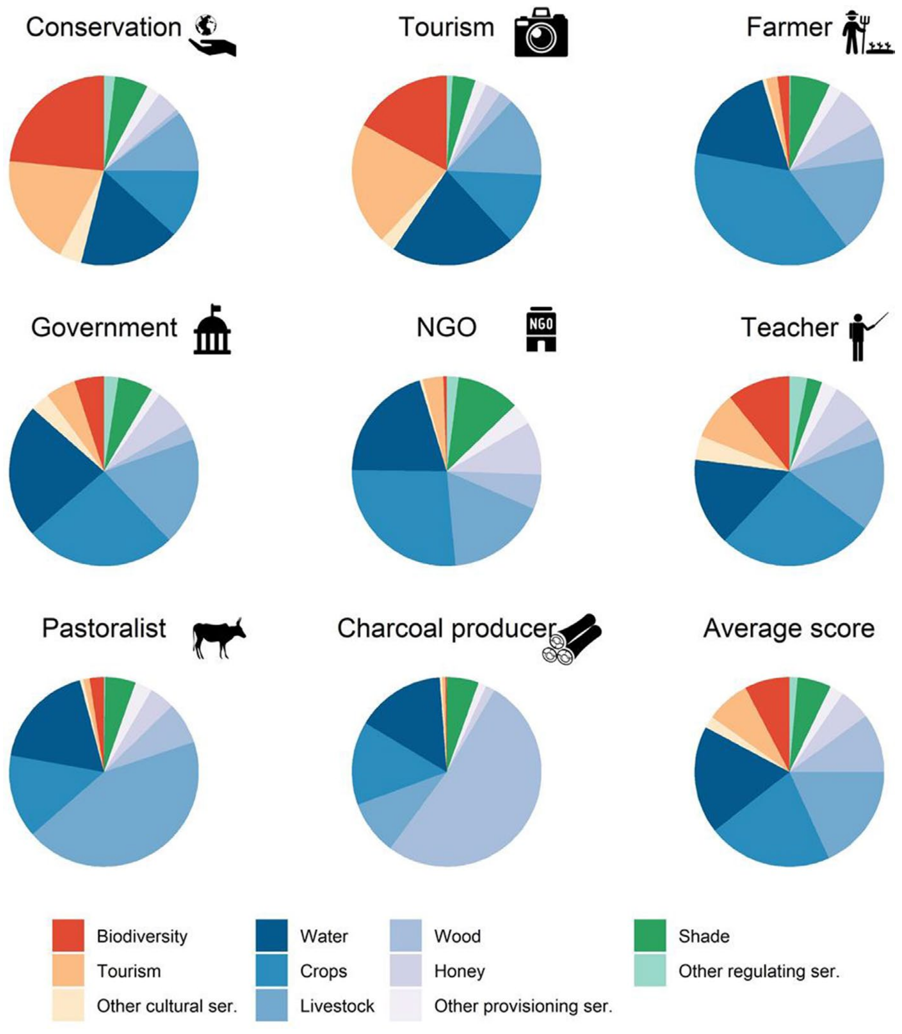

FIGURE 3 Ecosystem service priorities for each stakeholder group and the average priority scores of all stakeholder groups combined. Proportions shown are the mean for all respondents in the self-identified group. Red shades show cultural services, blue provisioning services and green regulating services

TABLE 1 Overview of the affiliations and distinguishing socio-economic characteristics of each stakeholder group and their sample sizes

Stakeholder group	Sample size	Stakeholder identity	Distinguishing socio-economic characteristics
Charcoal producer	32	Charcoal producers and charcoal association leaders	Poorly educated, low land and livestock ownership, equal gender representation (other groups more male-dominated)
Conservationist	25	Kenya Wildlife Service, Kenya Forest Service, Northern Rangeland Trust, community conservancies	Highly educated, higher proportion of immigrants
Crop farmer	42	Crop farmers	High land ownership, medium education level, medium livestock ownership
Developmental NGO's	9	Medical aid and development organizations: Kenyan Red Cross, Baringo Network Ministries, Kerio Valley Development Authority	Highly educated, low land ownership
Government official	53	Village (assistant) chiefs and (sub-) location, ward and county government agencies	Most highly educated, medium land and livestock ownership
Pastoralist	28	Pastoralists	High landownership, medium education level, high livestock ownership
Teacher	11	Primary and secondary school teachers	Highly educated
Tourism industry	34	Tourist lodge and tourist guide association employees	Highly educated, higher proportion of immigrants, higher land ownership

homes. Additionally, hotels, tourism guide associations, conservation organizations, government offices and NGO offices were visited throughout the study area. Within each institution, 3–10 people were interviewed separately, depending on the size of the institution. In institutions, the interviewees were selected by a supervisor to cover different hierarchical layers (e.g. from desk clerks to general managers) and interviewees were selected on availability. All interviewees were adults at the time of the study. Interviews were performed by a team of 10 trained enumerators, who had previous experience in administering questionnaires and who were fluent in the local languages, and the questionnaire was pre-tested on roughly 15 villagers and natural resource management specialists.

Each stakeholder was asked which of the pre-defined stakeholder groups they identified as belonging to most closely. To measure the relative priority of multiple ecosystem services, each stakeholder was then asked to divide 20 points, represented by dried beans, across 15 potentially relevant ecosystem services (see Table 2). The meaning of all ecosystem services was explained by the enumerators. In addition, ecosystem services were represented by pictures depicting examples of this service when possible (see Supporting Information 1). Ecosystem services were selected a priori by researchers with experience in the region, and a group of local people, based on the *Common International Classification of Ecosystem Services* (CICES) classification (Potschin & Haines-Young, 2016). We included only services with a direct link to final benefits (as defined in the cascade model; Potschin-Young et al., 2018), to minimize the misallocation of points between final benefits and the regulating services which underpin these. Interviewees were also given the option to name additional services which they deemed important and allocate points to them. The number of points to be distributed was limited to encourage stakeholders to prioritize, as otherwise stakeholders could assign high or low scores to all services (e.g. Washbourne et al., 2020). This method, which we term ecosystem service priority assessment (ESPA), was adapted from previous measures of ecosystem service priority (Washbourne et al., 2020) but tailored to generate values that can be used in the ecosystem service multifunctionality approach described above. This approach also allows multiple values of a single service (e.g. relational and material; Chan et al., 2012) to be integrated without double counting. Discussion with stakeholders while conducting the interviews indicated that stakeholders were aware of interdependencies between services and allocated their points accordingly. For example, those from the ecotourism sector gave points to both tourism and conservation, and farmers and pastoralists gave points to water. Nevertheless, overlap between certain services, for example, (eco)tourism and biodiversity, and water and crop production could not be avoided altogether, meaning some points may be misallocated, and the demand for regulating services that underpin these final benefits may be underrepresented. The priority some services that are currently at high supply may also be 'taken for granted' and so their priority underestimated.

Each stakeholder had to allocate all points, with more points allocated to ecosystem services that they had a higher priority for. Stakeholders were asked to perform this exercise three times: for the current situation, for the coming year and for 20 years into the future, to identify any potential differences between current and long-term interests. Additionally, each stakeholder was asked to explain their point distribution and to provide general data on their

TABLE 2 Overview of the ecosystem services considered in this study and for the services used in the multifunctionality calculations and their method

Ecosystem service class	Specific service	Indicator of ecosystem service supply
Cultural	Biodiversity conservation	Plant species richness from vegetation relevees
	Tourism	Presence of charismatic large animal species. Assessment of potential presence based on habitat preferences
	Medicinal plants	NA[a]
	Presence of sacred sites/ burial places	NA[a]
	Landscape beauty	NA[a]
	Presence of culturally important plants or animals	NA[a]
Provisioning	Crop production	Assumed to be zero
	Livestock production	Fodder production of both Prosopis seed pods and herbaceous biomass
	Fishing	NA[a]
	Honey production	Flower abundance extrapolated based on Prosopis pod counts and herbaceous plant cover
	Woody biomass for charcoal/firewood	Standing woody biomass of Prosopis (kg) using allometric equations
	Water availability	Groundwater use of Prosopis (L/ day) based on sap flow and evapotranspiration
Regulating	Shade	Woody species cover (%)
	Protection against insect-borne diseases	NA[a]
	Carbon storage	NA[a]

[a]Services denoted as NA were present in the questionnaire but not prioritized by any stakeholder groups (<5% of points allocated in all stakeholder groups)

education, age, gender, land ownership and ethnicity (tribal association). The full questionnaire is found in Supporting Information 1. For the calculation of multifunctionality, we excluded ecosystem services which were not given an average points allocation of >5% by any stakeholder group, leaving us with eight services that were of importance to at least one group. These were as follows: the cultural services of biodiversity conservation and tourism, the provisioning services of crop production (crops hereafter), wood production (wood), livestock production (livestock), water supply (water) and honey production (honey), and one regulating service, shade provision (shade).

The pre-defined stakeholder groups give a clear overview of the different priorities of the main profession-related groups. In contrast, defining groups by the statistical similarity of priority scores allows for the identification of patterns of similar priority across stakeholder groups that may be associated with factors other than profession, for example, cultural or demographic. Identification of such groups can aid management by identifying bundles of commonly co-prioritized services. To calculate such groups, we created a similarity index based on Euclidean distances and used NMDS as a clustering tool (see Supporting Information 2 for more details).

2.3.2 | Ecological data

Ecological data were used to estimate levels of ecosystem service supply and the extent of *Prosopis* invasion. Data on the ecological impact of Prosopis on ecosystem properties were collected along a Prosopis cover gradient ranging from 0% to 80% cover in 15 × 15 m plots. A total of 67 plots were sampled in the rainy seasons of 2016 and 2017. In all, 5–8 plots were selected in each of 10 sub-locations, the smallest administrative unit in Kenya. Within each sub-location, plots were selected along a Prosopis cover gradient and plots within one sub-location all had a similar land use history, though land use history could differ between sub-locations; see Linders et al. (2019) for more details. The plot-level properties were used as indicators for ecosystem service supply according to the methods mentioned in Table 2. For details of the measurement methodology, see Supporting Information 3.

2.4 | Statistical analysis

2.4.1 | Impact of Prosopis on ecosystem service supply and prioritization

We first assessed how the supply of each individual ecosystem service was affected by Prosopis invasion using regressions with individual ecosystem services as dependent variables and Prosopis cover as the independent variable in R version 3.6 (R Development Core Team 3.6., 2019). We also assessed how the priority scores differed between the different stakeholder groups by comparing the points allocated to each service using a Kruskal–Wallis test with a pairwise Wilcoxon test as the post-hoc.

2.4.2 | Quantification of multifunctionality

Using the ecosystem service multifunctionality approach, we assessed how Prosopis invasion affected each stakeholder group. First, each ecosystem service supply indicator was standardized between 0 and 1, using the 95% percentile as the maximum to correct for potential outliers. As crop production in our plots was impossible under current vegetation cover, all plots were assigned a value of 0 for crop production. Next, the supply–benefit relationship was applied to each service. For most services, a linear 1:1 relationship between ecosystem service supply and stakeholder benefit was assumed, as there was no reason to expect the saturation of demand within the observed range of these degraded ecosystems, and it was deemed likely that even low levels of service supply would still be valued. The exception was shade, for which we used a threshold point of 50% tree cover, above which there is no further benefit. This was based on responses from interviewees who were asked to identify an optimum of tree cover. This means that we rescaled all cover values with >50% tree cover to the maximum value. For shade, we thus used a segmented regression from the package SEGMENTED (Muggeo, 2019) to assess the relationship between shade and Prosopis cover up to 50%.

Multifunctionality was calculated for each plot for each stakeholder group by multiplying the individual standardized ecosystem service benefit values by the average proportion of priority points allocated to each service by the stakeholder group (see Figure 2 and Manning et al. 2018 for further details). This was done both for the pre-defined stakeholder groups and the data-defined groups. For the pre-defined groups, we averaged the priority scores from the three time periods, as we argue that a combination of short- and long-term priorities is most reflective of stakeholder wishes, even though only small differences exist between the time steps (see Supporting Information 4). In addition to the stakeholder priority-based analysis, we also analysed how multifunctionality was affected by Prosopis when all indicators were given equal weight, using the averaging approach (Byrnes et al., 2014), thus allowing the comparison of our results with those of previous multifunctionality studies (Hölting et al., 2019; Maestre et al., 2012; van der Plas, Manning, Allan, et al., 2016). We tested whether ecosystem multifunctionality for each stakeholder group was significantly affected by Prosopis cover using linear regressions. To assess the robustness of our multifunctionality results, we additionally performed a sensitivity analysis in which we changed the supply–benefit relationship for each ecosystem service to an alternative plausible form (see Supporting Information 5 for details). With the exception of water, which showed some moderate sensitivity, changing the supply–benefit relationship did not affect the relationship between Prosopis cover and individual services, or ecosystem service multifunctionality, for any of the stakeholder groups.

3 | RESULTS

3.1 | Prosopis effects on ecosystem service supply

The invasion of Prosopis onto degraded land had mixed effects on ecosystem service supply (Table 3). Increasing Prosopis cover significantly increased the supply of shade, wood and honey, but significantly and negatively affected potential water supply, biodiversity conservation and tourism potential. It did not significantly affect livestock (fodder availability), which was already low.

3.2 | Ecosystem service priorities of stakeholders

There were clear differences in which ecosystem services were prioritized by different stakeholder groups. However, most stakeholder groups prioritized provisioning services: charcoal producers, farmers, government officials, developmental NGO workers and pastoralists all allocated >75% of their points to provisioning services (Figure 3). Cultural services were only important to conservationists (46%) and the tourism industry (41%) and had some importance to teachers (23%) and government officials (13%). Regulating services were allocated only 5%–8% of the points from all stakeholder groups, except regional development agencies (13%). Conservationists prioritized biodiversity conservation more than all other stakeholder groups (23%; $p = 0.02$). Both teachers and the tourism industry also prioritized biodiversity conservation compared to other stakeholder groups (11% and 17%, respectively; $p = 0.04$). Tourism received more points from the conservationist and tourism industry groups compared to the other groups (19% and 21% respectively; $p < 0.01$). Charcoal burners prioritized wood far more highly than any other stakeholder group (52%; $p < 0.0001$), (maximum for other groups 7%), and wood was given lower priority by conservationists and tourism industry compared to other groups (1% and 2%, respectively; $p = 0.03$). Priority for crops was relatively evenly distributed, as each group assigned more than 10% of their points to crops, but it was higher among farmers compared to all other stakeholder groups (38% of points; $p = 0.04$), except for regional development agencies (27%; $p = 0.07$). Pastoralists showed a significantly higher priority for livestock than any other stakeholder group (44%; $p < 0.01$). Water was important to all stakeholder groups, but particularly government officials, compared to charcoal producers, conservationists and farmers (23%; $p = 0.03$) and for tourism industry compared to charcoal producers (21%; $p = 0.01$). There was no significant difference in the prioritization of shade between the stakeholder groups ($p > 0.25$).

There were four data-defined stakeholder groups (Supporting Information 2), each prioritizing specific services: charcoal, livestock production, crop production and tourism and biodiversity conservation. These overlap considerably with the self-identified groups, indicating that there are no major ES priority groups outside the predefined occupational ones.

Priority scores were relatively unaffected by current and long-term perspectives, with responses relatively similar for each of the time steps: current, the coming year and long-term future. The only change was that the diversity of point distribution (Shannon–Wiener index) declined in the future scenarios compared to the current situation. This was caused by stakeholders putting even higher future priority on ecosystem services which were already prioritized (Supporting Information 4).

3.3 | Prosopis effects on ecosystem service multifunctionality

Increasing Prosopis cover provides a net benefit to only two groups, charcoal burners (Figure 4; $p < 0.0001$) and developmental NGOs ($p = 0.001$; Supporting Information 6 for raw graphs) but significantly decreases ecosystem service multifunctionality for conservationists ($p < 0.0001$), government officials ($p = 0.01$), teachers ($p = 0.005$) and the tourism industry ($p < 0.0001$). The negatively impacted groups prioritize water, biodiversity and tourism, whereas those prioritizing wood, honey and shade benefit from the invasion. For farmers ($p = 0.23$) and pastoralists ($p = 0.32$), Prosopis cover did not affect ecosystem service multifunctionality. Average multifunctionality was relatively low for farmers across the whole cover gradient (<0.4), due to the lack of crops on the study plots.

TABLE 3 Regression summary of Prosopis effects on standardized ecosystem service supply indicators

Ecosystem service	Estimate	*SE*	*p* value	R^2
Biodiversity conservation	−0.003	0.001	**<0.01**	0.10
Tourism	−0.007	0.001	**<0.0001**	0.29
Water supply	−0.01	0.0009	**<0.0001**	0.62
Wood	0.007	0.0009	**<0.0001**	0.55
Livestock	−0.002	0.001	0.16	0.03
Honey	0.008	0.001	**<0.0001**	0.52
Crops	NA	NA	NA	NA
Shade <50%	0.02	0.002	**<0.0001**	0.79
Shade >50%			NA	0.79

Bold indicates $p < 0.05$.

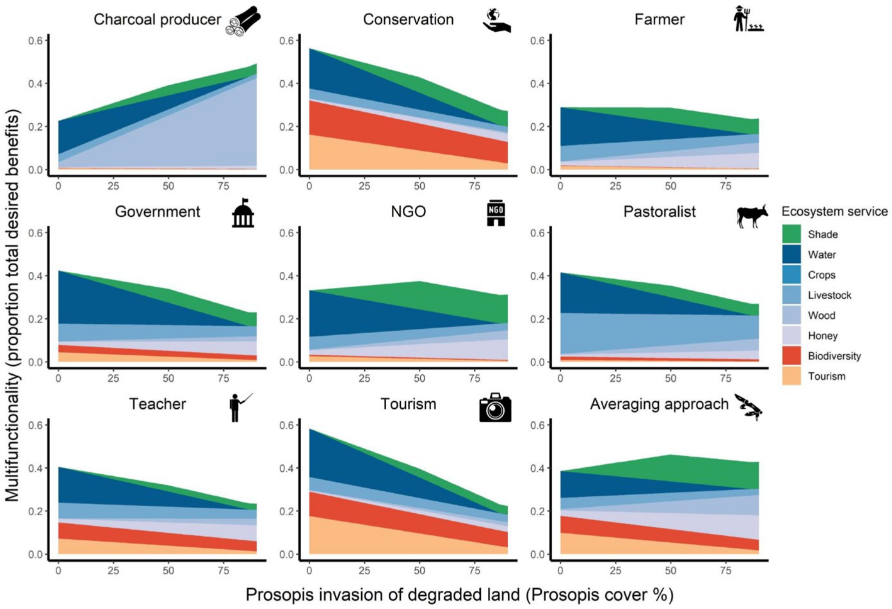

FIGURE 4 The impact of increasing Prosopis cover on ecosystem service multifunctionality, and its component ecosystem services, for multiple stakeholder groups. Lines shown are individual regressions for each service and for multifunctionality, their sum. The contribution of each service shown is standardized supply converted to benefit and multiplied by its priority score for that group. A multifunctionality score of 1 indicates that all ecosystem service demands are met fully. Crops were prioritized by all stakeholders but had a supply value of zero across the entire study gradient, thus limiting total ecosystem service multifunctionality

Sensitivity analyses showed that these results are largely robust (Supporting Information 5). Ecosystem service multifunctionality was rarely higher than 0.5, the exceptions being for charcoal producers, at high cover, and conservation and tourism industry employees, at low cover. The reason for this was that some services, for example, crops, were not supplied at all, while for others the simultaneously high supply of all prioritized services was precluded by trade-offs in supply along the Prosopis gradient. When weighing all services equally, using a standard averaging approach, Prosopis cover significantly increases overall ecosystem service multifunctionality ($p = 0.002$). When averaging the mean priority scores of each stakeholder group to estimate how Prosopis affects ecosystem service multifunctionality for the whole community (assuming equal weighting of each group), Prosopis had no significant effect on ecosystem service multifunctionality ($p = 0.11$), in keeping with its status as a conflict-of-interest species.

4 | DISCUSSION

Our results show that the impact of an invasive tree on ecosystem service multifunctionality depends strongly on the relative priorities given to different ecosystem services by stakeholders, with impacts varying from positive to negative depending on stakeholder group identity. Ecosystem service multifunctionality, a measure of overall ecosystem service supply relative to stakeholder demand, declined for most stakeholder groups with increasing Prosopis invasion in degraded land, but two groups, charcoal producers and developmental NGOs, benefited from an increase in Prosopis cover. From a methodological perspective, we show that the ecosystem service multifunctionality approach provides a detailed description of synergies and trade-offs between multiple ecosystem services, at the levels of both supply and priority, and how these affect overall multifunctionality for multiple stakeholder groups. A comparison of results from this approach with those generated by the averaging method also highlights that the ecosystem service multifunctionality approach can identify and quantify more realistic and nuanced relationships between global change drivers and society than other multifunctionality approaches. In turn, this information may be used to help identify land management strategies that minimize trade-offs, and thus conflict between stakeholders.

4.1 | Patterns of ecosystem service priorities

In general, most stakeholders prioritized provisioning ecosystem services, with only conservationists and tourism industry employees prioritizing cultural services. As the local population in our study area is generally poor and mostly rural, this supports the hypothesis of Yahdjian et al. (2015) that such stakeholders strongly prioritize provisioning services. As also identified by Martín-López et al. (2012), the stakeholder groups which prioritize cultural services are relatively highly educated. In higher-income countries, a shift away from the prioritization of provisioning services can be explained by economic diversification, and a decline in the relative economic importance of agriculture (Anderson, 1987). This shift can be seen in Baringo, Kenya, as the stakeholder groups which prioritized cultural services were economically dependent upon conservation and tourism, and these are relatively new and increasingly important industries (Valle & Yobesia, 2009). With the exception of government officials, developmental NGO employees and teachers all the stakeholder groups in our study depend directly on the supply of ecosystem services and unsurprisingly, each group gave priority to the service on which their income depends, for example, farmers placed highest importance on crop production. Similar patterns of ecosystem service priority across stakeholder groups are also apparent elsewhere. In the Austrian Alps, Zoderer et al. (2019) found that visitors prioritized cultural services, locals prioritized regulating services and farmers the provisioning services on which their income depends. In Spain, similar conflicts arose as each stakeholder groups prioritized ecosystem services that were relevant to them professionally, for example, provisioning services for farmers and regulating services for environmental professionals (Iniesta-Arandia et al., 2014). Whether stakeholders were considering current or future demand had little impact on demand for all stakeholder groups (Supporting Information 4), indicating that they expect that the services they desire now will also be those prioritized in the future. However, stakeholders tended to focus their future priorities upon services they already deemed important. This strategy could be driven by increasing specialization of labour—a common property of economic development (Papageorgiou & Spatafora, 2012) that may limit adaptation options (Wuepper et al., 2018).

4.2 | Prosopis effects on ecosystem service multifunctionality

Our results, the first to use real stakeholder data with the ecosystem service multifunctionality approach, show that stakeholder perception can shape both the sign and strength of the relationship between a global change driver and multifunctionality. Whether Prosopis invasion changes ecosystem service multifunctionality depends on how strongly certain services are prioritized by the stakeholder group in question, and how strongly these prioritized services react to Prosopis. Only two stakeholder groups benefit from Prosopis invasion of degraded land: charcoal producers and developmental NGOs. Charcoal producers benefit mainly due to their high priority for wood, the availability of which strongly increases with Prosopis cover. Economically poor stakeholders are typically expected to have limited capacity to adapt to environmental change (Ariti et al., 2015). However, here charcoal producers, which are lowly educated and own little land and livestock, benefit strongly from Prosopis invasion, as producing charcoal needs very little investment. This indicates that they have made opportunistic use of an emerging resource. Developmental NGO's benefit because they give relatively high priority to shade and honey production, two services that respond positively to increasing Prosopis cover. Whereas in our heavily degraded study system wood, shade and honey are all strongly related to Prosopis, this does not mean that on a larger-scale Prosopis is also beneficial to these stakeholder groups. Native woody species that can also provide these services still dominate other areas in the region (Mbaabu et al., 2019), without the clear trade-offs of Prosopis.

The decline of ecosystem service multifunctionality with invasion for several stakeholder groups was mainly due to Prosopis reducing water availability, biodiversity and tourism potential. Neither pastoralists nor farmers were impacted significantly, but they had relatively low multifunctionality values across the entire Prosopis cover gradient. The lack of impact on pastoralists can be explained by the fact that sampling took place on heavily degraded, and often historically overgrazed sites, where herbaceous fodder was low even before Prosopis invasion (Mbaabu et al., 2019). Prosopis invasion of non-degraded grasslands results in strongly negative effects on fodder availability (Linders et al., 2019; Shackleton et al., 2014) and is thus likely to negatively affect ecosystem service multifunctionality for pastoralists. This highlights the context dependency of the impact of global change drivers on multifunctionality (Allan et al., 2015; Giling et al., 2019). Additionally, these different ecosystem service multifunctionality effects explain how differences in perception of which services are important can lead to mixed perceptions of an invasive species within societies (Shackleton et al., 2019).

We could not include Prosopis impacts on crop production in our study, as we did not have any data on Prosopis effects on arable land and crop production in the current plots would likely reduce the supply of other services measured in our plots. Exclusion of crops in this study explains the lack of Prosopis effect found for farmers, as their most prioritized service could not be provided by any of the plots included in our study, leading to low overall ecosystem service multifunctionality. Prosopis would shade out crops and is known to alter soil chemistry (Linders et al., 2019; Shackleton et al., 2014). Furthermore, there would be a cost to clearing Prosopis before crop production can start (Swallow & Mwangi, 2008) Therefore, we expect that Prosopis effects on multifunctionality for farmers would be more negative if a comparison was made with the less degraded areas and croplands that were not included in this study.

When weighing all services equally, Prosopis was found to have a net positive effect on ecosystem service multifunctionality. In contrast, by using an average stakeholder group response to weight, each service Prosopis was shown to have net neutral effect. This demonstrates that Prosopis is a conflict-of-interest species in our study area, and that basing ecosystem management on equal weighting multifunctionality measures is inadvisable. Such trade-offs between different stakeholder groups are common when each profits from a specific provisioning service (Howe et al., 2014). Therefore, our results further highlight the need to incorporate stakeholder priorities into research that investigates the impacts of global environmental change.

4.3 | Future approaches and management implications

This study was based on snapshot measurements of supply taken at the plot scale, and thus lacks a representation of the spatial and a temporal heterogeneity and dynamics of landscapes. Given the role of croplands and other tree species in providing ecosystem services within the study region, it is clear that a landscape-scale evaluation of multifunctionality (Manning et al., 2018; van der Plas et al., 2019) that incorporates a wider range of land uses is needed before clear management recommendations on Prosopis management can be given. However, it is clear that lower Prosopis cover would benefit most stakeholders, and would only be detrimental for charcoal producers, if no native trees are present. Despite these limitations, the relationships identified here could be presented to stakeholders as a means of fostering understanding between them, and to managers who must balance the needs of multiple groups. Apps and other communication tools may also enable the communication of such findings, for example, by showing how sensitive the results are to the supply and priority aspects (Neyret et al., 2020). The results may also help in finding common goals between different stakeholder groups. Experience in invasive plant management has shown that focussing management on a few services, which all stakeholders agree are important, can be effective (van Wilgen & Wannenburgh, 2016). Here, all stakeholder groups agreed on the importance of water, crop production, and at a lower level, shade. These are thus the foundational services that any management plan should include.

Future landscape-scale approaches should ideally also incorporate information on where services are demanded via spatially explicit supply − benefit relationships (Manning et al., 2018), For example, shade may only be demanded near villages. Improved indicators that better reflect the services prioritized could also be used. For example, for biodiversity conservation the landscape abundance of animals of conservation concern, rather than measures of plot-scale plant diversity. Upscaling our results to a landscape level should also allow us to assess whether a mixed landscape of both Prosopis and uninvaded sites could provide high ecosystem service multifunctionality to multiple groups, as services that trade-off at the plot scale could be provided by different areas. Such a possibility is suggested by both empirical and theoretical studies (van der Plas et al., 2019; van der Plas, Manning, Soliveres, et al., 2016), although very high levels of all services at the landscape scale are impossible where such trade-offs occur (Neyret et al., 2020; van der Plas et al., 2019). Temporal aspects would further enhance the multifunctionality approach and its applicability in addressing sustainable management problems. This may include factors such as the changing of stakeholder priorities over time (Koch et al., 2009).

More accurate supply–benefit relationships would also be advantageous, as while our results were largely insensitive to supply–benefit relationships we used, these can strongly affect multifunctionality metrics (Manning et al. 2018). These could incorporate changes in the relationship between drivers and supply, for example, as caused by unsustainable land use practices and resource use (Geijzendorffer et al., 2015). Currently, our supply–benefit relationships do not capture certain real dynamics such as changes to the maximum and minimum supply of services, since benefit is capped at 1 at the observed maximum supply of a specific land use type, nor corresponding changes in demand, for example, if demand saturates following management changes that create greater supply. Regulating services that underpin the sustainability of ecosystem service supply may also be undervalued by our approach, as by working at the level of final benefits their continued supply is somewhat assumed.

Another aspect that may require refinement is the link between the services prioritized between stakeholders, and the indicators used. Mismatches and the misallocation of priority points may occur due to mutual failure to communicate the services discussed precisely, or the lack of high-quality indicators. Misallocation is most likely to occur for cultural ecosystem services and is most problematic if these services respond differently to the driver. However, we feel this was unlikely in our study as most cultural services were related to natural and biodiverse ecosystems. Finally, we did not investigate relationships between stakeholders, even though these clearly shape priorities, and land use decisions (Reed et al., 2009). Understanding which stakeholders are powerful and how different stakeholder groups are interrelated is crucial, as different stakeholders might have the power to influence the supply of specific services and management decisions (Felipe-Lucia et al., 2015).

4.4 | Conclusions

In this study, we combined social science data on ecosystem service priorities with detailed natural science data describing the impact of an invasive tree on the supply of ecosystem services. This allowed us to holistically assess the overall impact of a global change driver on stakeholder benefits, in terms of its net overall impact and the relative impact on different stakeholder groups. We also show that ecosystem service multifunctionality measures can be used to aid decision making and the identification of land management options. The collection of stakeholder priority scores should therefore be seen as a relatively small investment, but with high gains in terms of relevance, for the many research projects that seek to identify how environmental change drivers affect ecosystem services and the people that depend upon them.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

T.E.W.L., U.S., E.A. and P.M. designed the study; T.E.W.L. and H.S. performed the field work and S.K.C. provided the logistical support in the field; T.E.W.L. performed the analyses and wrote the first draft. All authors contributed to data collection and all authors contributed substantially to revisions.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository https://doi.org/10.5061/dryad.573n5tb6s (Linders et al., 2021).

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REFERENCES

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., Böhm, S., Grassein, F., Hölzel, N., Klaus, V. H., Kleinebecker, T., Morris, E. K., Oelmann, Y., Prati, D., Renner, S. C., Rillig, M. C., Schaefer, M., Schloter, M., Schmitt, B., … Fischer, M. (2015). Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. *Ecology Letters*, *18*, 1–10. https://doi.org/10.1111/ele.12469

Anderson, K. (1987). On why agriculture declines with economic growth. *Agricultural Economics*, *1*(3), 195–207. https://doi.org/10.1016/0169-5150(87)90001-6

Ariti, A. T., van Vliet, J., & Verburg, P. H. (2015). Land-use and land-cover changes in the Central Rift Valley of Ethiopia: Assessment of perception and adaptation of stakeholders. *Applied Geography*, *65*, 28–37. https://doi.org/10.1016/j.apgeog.2015.10.002

Barnes, A. D., Allen, K., Kreft, H., Corre, M. D., Jochum, M., Veldkamp, E., Clough, Y., Daniel, R., Darras, K., Denmead, L. H., Farikhah Haneda, N., Hertel, D., Knohl, A., Kotowska, M. M., Kurniawan, S., Meijide, A., Rembold, K., Edho Prabowo, W., Schneider, D., … Brose, U. (2017). Direct and cascading impacts of tropical land-use change on multitrophic biodiversity. *Nature Ecology and Evolution*, *1*(10), 1511–1519. https://doi.org/10.1038/s41559-017-0275-7

Bekele, K., Haji, J., Legesse, B., Shiferaw, H., & Schaffner, U. (2018). Impacts of woody invasive alien plant species on rural livelihood: Generalized propensity score evidence from Prosopis spp. invasion in Afar Region in Ethiopia. *Pastoralism*, *8*(1), 28. https://doi.org/10.1186/s13570-018-0124-6

Bernués, A., Rodríguez-Ortega, T., Alfnes, F., Clemetsen, M., & Eik, L. O. (2015). Quantifying the multifunctionality of fjord and mountain agriculture by means of sociocultural and economic valuation of ecosystem services. *Land Use Policy*, *48*, 170–178. https://doi.org/10.1016/j.landusepol.2015.05.022

Byrnes, J. E. K., Gamfeldt, L., Isbell, F., Lefcheck, J. S., Griffin, J. N., Hector, A., Cardinale, B. J., Hooper, D. U., Dee, L. E., & Emmett Duffy, J. (2014). Investigating the relationship between biodiversity and ecosystem multifunctionality: Challenges and solutions. *Methods in Ecology and Evolution*, *5*(2), 111–124. https://doi.org/10.1111/2041-210X.12143

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, *486*(7401). https://doi.org/10.1038/nature11373

Chan, K. M. A., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. *Ecological Economics*, *74*, 8–18. https://doi.org/10.1016/j.ecolecon.2011.11.011

Darvill, R., & Lindo, Z. (2015). Quantifying and mapping ecosystem service use across stakeholder groups: Implications for conservation with priorities for cultural values. *Ecosystem Services*, *13*, 153–161. https://doi.org/10.1016/j.ecoser.2014.10.004

Darvill, R., & Lindo, Z. (2016). The inclusion of stakeholders and cultural ecosystem services in land management trade-off decisions using an ecosystem services approach. *Landscape Ecology*, *31*(3), 533–545. https://doi.org/10.1007/s10980-015-0260-y

Defries, R., & Nagendra, H. (2017). Ecosystem management as a wicked problem. *Science*, *356*, 265–270. https://doi.org/10.1126/science.aal1950

Eckert, S., Hamad, A., Kilawe, C. J., Linders, T. E. W., Ng, W.-T., Mbaabu, P. R., Shiferaw, H., Witt, A., & Schaffner, U. (2020). Niche change analysis as a tool to inform management of two invasive species in Eastern Africa. *Ecosphere*, *11*(2). https://doi.org/10.1002/ecs2.2987

EW Linders, T., Bekele, K., Schaffner, U., Allan, E., Alamirew, T., Choge, S. K., Eckert, S., Haji, J., Muturi, G., Mbaabu, P. R., Shiferaw, H., & Eschen, R. (2020). The impact of invasive species on social-ecological systems: Relating supply and use of selected provisioning ecosystem services. *Ecosystem Services*, *41*, 101055. https://doi.org/10.1016/j.ecoser.2019.101055

Felipe-Lucia, M. R., Martín-López, B., Lavorel, S., Berraquero-Díaz, L., Escalera-Reyes, J., & Comín, F. A. (2015). Ecosystem services flows: Why stakeholders' power relationships matter. *PLoS ONE*, *10*(7), 1–21. https://doi.org/10.1371/journal.pone.0132232

Frei, B., Renard, D., Mitchell, M. G. E., Seufert, V., Chaplin-Kramer, R., Rhemtulla, J. M., & Bennett, E. M. (2018). Bright spots in agricultural landscapes: Identifying areas exceeding expectations for multifunctionality and biodiversity. *Journal of Applied Ecology*, *55*(6), 2731–2743. https://doi.org/10.1111/1365-2664.13191

Gamfeldt, L., Hillebrand, H., & Jonsson, P. R. (2008). Multiple functions increase the importance of biodiversity for overall ecosystem functioning. *Ecology*, *89*(5), 1223–1231. https://doi.org/10.1890/06-2091.1

Geijzendorffer, I. R., Martín-López, B., & Roche, P. K. (2015). Improving the identification of mismatches in ecosystem services assessments. *Ecological Indicators*, *52*, 320–331. https://doi.org/10.1016/j.ecolind.2014.12.016

Giling, D. P., Beaumelle, L., Phillips, H. R. P., Cesarz, S., Eisenhauer, N., Ferlian, O., Gottschall, F., Guerra, C., Hines, J., Sendek, A., Siebert, J., Thakur, M. P., & Barnes, A. D. (2019). A niche for ecosystem multifunctionality in global change research. *Global Change Biology*, *25*(3), 763–774. https://doi.org/10.1111/gcb.14528

Gos, P., & Lavorel, S. (2012). Stakeholders' expectations on ecosystem services affect the assessment of ecosystem services hotspots and their congruence with biodiversity. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*(1–2), 93–106. https://doi.org/10.1080/21513732.2011.646303

Grace, J. B., Anderson, T. M., Seabloom, E. W., Borer, E. T., Adler, P. B., Harpole, W. S., Hautier, Y., Hillebrand, H., Lind, E. M., Pärtel, M., Bakker, J. D., Buckley, Y. M., Crawley, M. J., Damschen, E. I., Davies, K. F., Fay, P. A., Firn, J., Gruner, D. S., Hector, A., … Smith, M. D. (2016). Integrative modelling reveals mechanisms linking productivity and plant species richness. *Nature*, *529*, 390–393. https://doi.org/10.1038/nature16524

Hector, A., & Bagchi, R. (2007). Biodiversity and ecosystem multifunctionality. *Nature*, *448*(7150), 188–190. https://doi.org/10.1038/nature05947

Hicks, C. C., Graham, N. A. J., & Cinner, J. E. (2013). Synergies and tradeoffs in how managers, scientists, and fishers value coral reef ecosystem services. *Global Environmental Change*, *23*(6), 1444–1453. https://doi.org/10.1016/j.gloenvcha.2013.07.028

Hölting, L., Beckmann, M., Volk, M., & Cord, A. F. (2019). Multifunctionality assessments – More than assessing multiple ecosystem functions and services? A quantitative literature review. *Ecological Indicators*, *103*, 226–235. https://doi.org/10.1016/j.ecolind.2019.04.009

Hooper, D. U., & Vitousek, P. M. (1998). Effects of plant composition and diversity of nutrient cycling. *Ecological Monographs*, *68*(1), 121–149.

Howe, C., Suich, H., Vira, B., & Mace, G. M. (2014). Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real world. *Global Environmental Change*, *28*, 263–275. https://doi.org/10.1016/J.GLOENVCHA.2014.07.005

Iniesta-Arandia, I., García-Llorente, M., Aguilera, P. A., Montes, C., & Martín-López, B. (2014). Socio-cultural valuation of ecosystem services: Uncovering the links between values, drivers of change, and human well-being. *Ecological Economics*, *108*, 36–48. https://doi.org/10.1016/j.ecolecon.2014.09.028

IPBES. (2018). In L. Montanarella, R. Scholes, & A. Brainich (Eds.), *The IPBES assessment report on land degradation and restoration*. https://doi.org/10.4324/9781315640051-105

Isbell, F., Reich, P. B., Tilman, D., Hobbie, S. E., Polasky, S., Binder, S., & Bren, D. (2013). Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(29), 11911–11916. https://doi.org/10.1073/pnas.1310880110

Kassilly, F. N. (2002). Forage quality and camel feeding patterns in Central Baringo, Kenya. *Livestock Production Science*, *78*(2), 175–182. https://doi.org/10.1016/S0301-6226(02)00032-5

Klain, S. C., & Chan, K. M. A. (2012). Navigating coastal values: Participatory mapping of ecosystem services for spatial planning. *Ecological Economics*, *82*, 104–113. https://doi.org/10.1016/j.ecolecon.2012.07.008

Koch, E. W., Barbier, E. B., Silliman, B. R., Reed, D. J., Perillo, G. M. E., Hacker, S. D., Granek, E. F., Primavera, J. H., Muthiga, N., Polasky, S., Halpern, B. S., Kennedy, C. J., Kappel, C. V., & Wolanski, E. (2009). Non-linearity in ecosystem services: Temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment*, *7*(1), 29–37. https://doi.org/10.1890/080126

Lavorel, S., Grigulis, K., Lamarque, P., Colace, M.-P., Garden, D., Girel, J., Pellet, G., & Douzet, R. (2011). Using plant functional traits to understand the landscape distribution of multiple ecosystem services. *Journal of Ecology*, *99*(1), 135–147. https://doi.org/10.1111/j.1365-2745.2010.01753.x

Linders, T. E. W., Schaffner, U., Alamirew, T., Allan, E., Choge, S. K., Eschen, R., Shiferaw, H., & Manning, P. (2021). Data from: Stakeholder priorities determine the impact of an alien tree invasion on ecosystem multifunctionality. *Dryad Digital Repository*, https://doi.org/10.5061/dryad.573n5tb6s

Linders, T. E. W., Schaffner, U., Eschen, R., Abebe, A., Choge, S. K., Nigatu, L., Mbaabu, P. R., Shiferaw, H., & Allan, E. (2019). Direct and indirect effects of invasive species: Biodiversity loss is a major mechanism by which an invasive tree affects ecosystem functioning. *Journal of Ecology*, *107*(6), 2660–2672. https://doi.org/10.1111/1365-2745.13268

Maestre, F. T., Quero, J. L., Gotelli, N. J., Escudero, A., Ochoa, V., Delgado-Baquerizo, M., Garcia-Gomez, M., Bowker, M. A., Soliveres, S., Escolar, C., Garcia-Palacios, P., Berdugo, M., Valencia, E., Gozalo, B., Gallardo, A., Aguilera, L., Arredondo, T., Blones, J., Boeken, B., … Zaady, E. (2012). Plant species richness and ecosystem multifunctionality in global drylands. *Science*, *335*(6065), 214–218. https://doi.org/10.1126/science.1215442

Manning, P., van der Plas, F., Soliveres, S., Allan, E., Maestre, F. T., Mace, G., Whittingham, M. J., & Fischer, M. (2018). Redefining ecosystem multifunctionality. *Nature Ecology & Evolution*, *2*(3), 427–436. https://doi.org/10.1038/s41559-017-0461-7

Maron, M., Mitchell, M. G. E., Runting, R. K., Rhodes, J. R., Mace, G. M., Keith, D. A., & Watson, J. E. M. (2017, April 1). Towards a threat assessment framework for ecosystem services. *Trends in Ecology & Evolution*, *32*, 240–248. https://doi.org/10.1016/j.tree.2016.12.011

Martín-López, B., Gómez-Baggethun, E., García-Llorente, M., & Montes, C. (2014). Trade-offs across value-domains in ecosystem services assessment. *Ecological Indicators*, *37*, 220–228. https://doi.org/10.1016/j.ecolind.2013.03.003

Martín-López, B., Iniesta-Arandia, I., García-Llorente, M., Palomo, I., Casado-Arzuaga, I., Amo, D. G. D., Gómez-Baggethun, E., Oteros-Rozas, E., Palacios-Agundez, I., Willaarts, B., González, J. A., Santos-Martín, F., Onaindia, M., López-Santiago, C., & Montes, C. (2012). Uncovering ecosystem service bundles through social preferences. *PLoS ONE*, *7*(6), e38970. https://doi.org/10.1371/journal.pone.0038970

Mbaabu, P. R., Ng, W.-T., Schaffner, U., Gichaba, M., Olago, D., Choge, S., Oriaso, S., & Eckert, S. (2019). Spatial evolution of prosopis invasion and its effects on LULC and livelihoods in Baringo, Kenya. *Remote Sensing*, *11*(10), 1217. https://doi.org/10.3390/rs11101217

Muggeo, V. M. R. (2019). *segmented V1.0*.

Muller, G. C., Junnila, A., Traore, M. M., Traore, S. F., Doumbia, S., Sissoko, F., Dembele, S. M., Schlein, Y., Arheart, K. L., Revay, E. E., Kravchenko, V. D., Witt, A., & Beier, J. C. (2017). The invasive shrub *Prosopis juliflora* enhances the malaria parasite transmission capacity of Anopheles mosquitoes: A habitat manipulation experiment. *Malaria Journal*, *16*(1), 237. https://doi.org/10.1186/s12936-017-1878-9

Mwangi, E., & Swallow, B. (2005). *Invasion of* Prosopis juliflora *and local livelihoods*. World Agroforestry Centre.

Neyret, M., Fischer, M., Allan, E., Hoelzel, N., Klaus, V., Kleinebecker, T., Krauss, J., Le Provost, J., Peter, S., Schenk, N., Simons, N. K., Van der Plas, F., Binkenstein, J., Boershig, C., Jung, K. G., Prati, D., Schäfer, D., Schaefer, H. M., & Schöning, I., … Manning, P. (2020). Landscape management for grassland multifunctionality. *BioRxiv*, 2020.07.17.208199. https://doi.org/10.1101/2020.07.17.208199

Papageorgiou, C., & Spatafora, N. (2012). Economic diversification in LICs: Stylized facts and macroeconomic implications. *Staff Discussion Notes*, *12*(13), 1. https://doi.org/10.5089/9781475532180.006

Pasiecznik, N. M., Felker, P., Cruz, G., & Cadoret, K. (2001). *The* Prosopis juliflora *– Prosopis pallida Complex : The* Prosopis juliflora *- Prosopis pallida Complex*. 172.

Plas, F., Allan, E., Fischer, M., Alt, F., Arndt, H., Binkenstein, J., Blaser, S., Blüthgen, N., Böhm, S., Hölzel, N., Klaus, V. H., Kleinebecker, T., Morris, K., Oelmann, Y., Prati, D., Renner, S. C., Rillig, M. C., Schaefer, H. M., Schloter, M., … Manning, P. (2019). Towards the development of general rules describing landscape heterogeneity–multifunctionality relationships. *Journal of Applied Ecology*, *56*(1), 168–179. https://doi.org/10.1111/1365-2664.13260

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land Use Policy*, *33*, 118–129. https://doi.org/10.1016/j.landusepol.2012.12.013

Potschin, M., & Haines-Young, R. (2016). Defining and measuring ecosystem services. In M. Potschin, R. Haines-Young, & R. K. Turner (Eds.), *Routledge handbook of ecosystem services* (pp. 25–44). Routledge.

Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K., & Schleyer, C. (2018). Understanding the role of conceptual frameworks: Reading the ecosystem service cascade. *Ecosystem Services*, *29*, 428–440. https://doi.org/10.1016/J.ECOSER.2017.05.015

R Development Core Team 3.6. (2019). *A language and environment for statistical computing*. R Foundation for Statistical Computing. Retrieved from http://www.r-project.org

Raymond, C. M., Bryan, B. A., MacDonald, D. H., Cast, A., Strathearn, S., Grandgirard, A., & Kalivas, T. (2009). Mapping community values for natural capital and ecosystem services. *Ecological Economics*, *68*(5), 1301–1315. https://doi.org/10.1016/j.ecolecon.2008.12.006

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*, *90*(5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Reynolds, C., Venter, N., Cowie, B. W., Marlin, D., Mayonde, S., Tocco, C., & Byrne, M. J. (2020). Mapping the socio-ecological impacts of invasive plants in South Africa: Are poorer households with high ecosystem service use most at risk? *Ecosystem Services*, *42*(July 2019), 101075. https://doi.org/10.1016/j.ecoser.2020.101075

Shackleton, R. T., Le Maitre, D. C., Pasiecznik, N. M., & Richardson, D. M. (2014). Prosopis: A global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. *AoB PLANTS*, *6*, 1–18. https://doi.org/10.1093/aobpla/plu027

Shackleton, R. T., Richardson, D. M., Shackleton, C. M., Bennett, B., Crowley, S. L., Dehnen-Schmutz, K., Estévez, R. A., Fischer, A., Kueffer, C., Kull, C. A., Marchante, E., Novoa, A., Potgieter, L. J., Vaas, J., Vaz, A. S., & Larson, B. M. H. (2019). Explaining people's perceptions of invasive alien species: A conceptual framework. *Journal of Environmental Management*, *229*, 10–26. https://doi.org/10.1016/j.jenvman.2018.04.045

Swallow, B., & Mwangi, E. (2008). *Prosopis juliflora* Invasion and Rural Livelihoods in the Lake Baringo Area of Kenya. *Conservation and Society*, *6*(2), 130. https://doi.org/10.4103/0972-4923.49207

Torralba, M., Fagerholm, N., Hartel, T., Moreno, G., & Plieninger, T. (2018). A social-ecological analysis of ecosystem services supply and trade-offs in European wood-pastures. *Science Advances*, *4*(5). https://doi.org/10.1126/sciadv.aar2176

Valle, E., & Yobesia, M. N. (2009). Economic contribution of tourism in Kenya. *Tourism Analysis*, *14*(3), 401–414. https://doi.org/10.3727/108354209789704986

van der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., Zavala, M. A., Hector, A., Ampoorter, E., Baeten, L., Barbaro, L., Bauhus, J., Benavides, R., Benneter, A., Berthold, F., Bonal, D., Bouriaud, O., Bruelheide, H., Bussotti, F., … Fischer, M. (2016). Jack-of-all-trades effects drive biodiversity–ecosystem multifunctionality relationships in European forests. *Nature Communications*, *7*, 11109. https://doi.org/10.1038/ncomms11109

van der Plas, F., Manning, P., Soliveres, S., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., Zavala, M. A., Ampoorter, E., Baeten, L., Barbaro, L., Bauhus, J., Benavides, R., Benneter, A., Bonal, D., Bouriaud, O., Bruelheide, H., Bussotti, F., Carnol, M., … Fischer, M. (2016). Biotic homogenization can decrease landscape-scale forest multifunctionality. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(13), 3557–3562. https://doi.org/10.1073/pnas.1517903113

van Wilgen, B. W., & Wannenburgh, A. (2016). Co-facilitating invasive species control, water conservation and poverty relief: Achievements and challenges in South Africa's Working for Water programme. *Current Opinion in Environmental Sustainability*, *19*, 7–17. https://doi.org/10.1016/j.cosust.2015.08.012

Villamagna, A. M., Angermeier, P. L., & Bennett, E. M. (2013). Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity*, *15*, 114–121. https://doi.org/10.1016/j.ecocom.2013.07.004

Washbourne, C.-L., Goddard, M. A., Le Provost, G., Manning, D. A. C., & Manning, P. (2020). Trade-offs and synergies in the ecosystem service demand of urban brownfield stakeholders. *Ecosystem Services*, *42*(January), 101074. https://doi.org/10.1016/j.ecoser.2020.101074

Wei, H., Fan, W., Wang, X., Lu, N., Dong, X., Zhao, Y., Ya, X., & Zhao, Y. (2017). Integrating supply and social demand in ecosystem services assessment: A review. *Ecosystem Services*, *25*, 15–27. https://doi.org/10.1016/J.ECOSER.2017.03.017

Woodford, D. J., Richardson, D. M., Macisaac, H. J., Mandrak, N. E., Van Wilgen, B. W., Wilson, J. R. U., & Weyl, O. L. F. (2016). Confronting the wicked problem of managing biological invasions. *NeoBiota*, *31*(31), 63–86. https://doi.org/10.3897/neobiota.31.10038

Wuepper, D., Yesigat Ayenew, H., & Sauer, J. (2018). Social capital, income diversification and climate change adaptation: Panel data evidence from Rural Ethiopia. *Journal of Agricultural Economics*, *69*(2), 458–475. https://doi.org/10.1111/1477-9552.12237

Yahdjian, L., Sala, O. E., & Havstad, K. M. (2015). Rangeland ecosystem services: Shifting focus from supply to reconciling supply and demand. *Frontiers in Ecology and the Environment*, *13*(1), 44–51. https://doi.org/10.1890/140156

Zoderer, B. M., Tasser, E., Carver, S., & Tappeiner, U. (2019). Stakeholder perspectives on ecosystem service supply and ecosystem service demand bundles. *Ecosystem Services*, *37*(June 2018), 100938. https://doi.org/10.1016/j.ecoser.2019.100938

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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