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Property rights play a pivotal role in the distribution of ecosystem services among beneficiaries

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ABSTRACT

Property rights are fundamental institutions that set the rules for who is allowed to use, manage, and control natural resources. Though the literature on property rights over natural resources is well developed. However, our understanding of the ways by which property rights govern actors' ability to obtain ecosystem services provided by these natural resources remains under-explored. Using the Adirondack Park, USA, as a case study, we develop a framework that pairs property rights theory with spatial analysis to show who can obtain ecosystem services across this landscape. We look at rights over three ecosystem services: timber, drinking water and recreational fishing. We show that property rights combined with ecosystem service flow affect who can receive ecosystem services, and where, across the landscape. Our results demonstrate that property rights can play a pivotal role in who can obtain ecosystem services across landscapes. However, more work is required to model the supply and flow of ecosystems services, and to connect these to property rights to fully capture the interactions occurring between property rights and ecosystem services, and how they influence who can obtain these services. This paper contributes to the literature by showing how property rights influence who the potential beneficiaries of ecosystem services are under different property rights regimes.

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1. Introduction

Ecosystem services – the ways in which nature contributes to human wellbeing – are essential to human wellbeing (IPBES 2019). Ecosystem services are produced by natural resources, such as water and forests, present within landscapes, and in combination with human actions that allow people to gain a benefit (Díaz et al. 2018). For example, agricultural production, an ecosystem service, is the result of, among other things, high-quality soils alongside ploughing and planting seeds. The mechanisms that influence natural resource management, such as governance and institutions, also play an important role in the ecosystem services that an area can supply and in determining who is allowed to access or obtain those services (Ban et al. 2015).

The ecosystem services supplied by a parcel of land are determined by both the biophysical conditions of the property and the landowner(s) or managers' actions and choices, which are in turn constrained by property rights, the collection of rights that define who is authorised to undertake particular actions in relation to managing a resource, including duties to preserve or protect it (Schlager and Ostrom 1992; Demsetz 2000; Lant et al. 2008). Property rights can define, for example, which trees can be harvested for timber (Cameron

et al. 2014), or the land parcels from which non-forest products can be harvested (Robinson et al. 2013). The impact of property rights on natural resource management is well studied, and a plethora of studies have assessed how natural resource management is regulated by property rights, such as how much timber is allowed to be harvested, or how waterways are allowed to be managed on a property, affect ecosystem service supply (Ostrom 1990; Bromley 1991; Martinez-Harms et al. 2015).

Just as property rights shape the actions of land managers, and thus the supply of ecosystem services, they can, alongside social-cultural factors such as values, also determine who can and cannot obtain, and benefit from, the ecosystem services that are supplied by a property (Sikor et al. 2017). In this way, property rights constrain who could receive an ecosystem service provided by a landscape, underpinning current debates around protection or dissolution of public lands (e.g. Felton 2017). For example, property rights dictate which people are allowed to harvest non forest timber products, such as mushrooms, on a property and gain an ecosystem service benefit (Robinson et al. 2013).

To date, research that empirically examines the role of property rights in shaping the question of 'who benefits' from environmental resources has largely

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used people's proximity to natural resources as a proxy for who can obtain ecosystem services (Pagella and Sinclair 2014). That is, researchers tend to assume that people can obtain any service that is provided near to them. Far less attention has been given to how property rights affect which populations are allowed to obtain, or are restricted from obtaining, ecosystem services from natural resources on land parcels across landscapes (Robinson et al. 2018). Yet, understanding this analytic layer is imperative to being able to assess how changes in natural resources (and thus a landscape's ecosystem services) relate to equitable access to ecosystem service benefits.

In this paper, we pair property rights theory with spatial analysis to determine how the property rights, and the actions they allow or prevent, affect the potential ecosystem services several beneficiary groups can obtain across a landscape. We use a simplified version of ecosystem services supplied by the Adirondack Park in New York, USA, as a case study. We first create a conceptual framework that outlines our approach for examining how property rights affect who can obtain ecosystems services. We then apply this conceptual framework to the Adirondack Park landscape to identify i) who has the right to obtain ecosystem services from each property, and ii) how these rights shape the spatial distribution of locations where different beneficiary groups can potentially obtain ecosystem services across the landscape.

2. Conceptual framework of property rights

Ecosystem services flow from the structure, process, and functions of ecosystems, in what is often referred to as the ecosystem service cascade (Haines-Young and Potschin 2010), to people who we call 'beneficiaries' because they benefit from the service. Such benefits can be the result of services co-produced with other inputs, such as human labor, as well as social-cultural characteristics of the potential beneficiary, such as their socio-economic status or values (Fisher et al. 2009). Some scientists further classify ecosystem services into intermediate and final services, where final services have an explicit and direct connection to human wellbeing (Wong et al. 2015). In this paper, we focus on final ecosystem services.

To receive an ecosystem service, the beneficiary must be able to obtain it. If an ecosystem service provides a benefit in the same location that it is produced, a person must be able to access the area where the service is supplied, such as visiting a property for recreation (Dade et al. 2020). If the benefit is provided in a different location to where the service is supplied, the person may receive a benefit by accessing a different area to where these service is supplied, as observed with flood mitigation where

wetlands on one property may improve flood mitigation on downstream properties as well (Tang et al. 2020). Finally, an ecosystem service may be obtained from anywhere if the benefit is not spatially restricted, such as carbon storage (Burkhard et al. 2014). The movement of ecosystem services to beneficiaries is referred to as ecosystem service flow (Villamagna et al. 2013). While a benefit from many ecosystem services can be obtained indirectly, through purchasing timber or food from the harvester, our study focuses specifically on the material benefits a person may obtain directly, such as the benefit received by the person harvesting the timber.

How ecosystem services produced within a landscape flow to beneficiaries is in part determined by property rights. While attention thus far has largely focused on how rights affect landholders' natural resource management and thus the *supply of* ecosystem services, property rights also affect who can *receive* ecosystem services. Two of the most commonly referenced frameworks related to usage rights are the access framework (Ribot and Peluso 2003) and the bundle of rights framework (Schlager and Ostrom 1992). Ribot and Peluso (2003) discuss *access* as an ability to derive ecosystem service benefits from a property based on various social relationships and mechanisms, thus focusing on power relations and the social embeddedness of rights, rather than on the flow of the ecosystem service benefit (e.g. does a person need to be on the property to derive a benefit, and does the person need to harvest natural resources to obtain a benefit). With a focus on rights, the 'bundle of rights' framework (Schlager and Ostrom 1992) characterizes different rights a person may be entitled for a given resource. The bundle of rights framework is useful for analysing the role of property rights on ecosystem service beneficiaries as it describes rights that allow (or prevent) one to use, manage, and control ecosystem services produced by the natural resources on a property, as demonstrated in Quinn et al. (2010), and is the framework we use in this paper. Property rights refer generally to things of value over which one may have rights. Therefore, in this paper, rights over 'property' generally indicates rights to a flow of a particular ecosystem service from a parcel of land. According to the bundle of rights framework, the core property rights a person can have consist of:

- (1) Access: the right to enter a property. This can restrict potential beneficiaries from receiving ecosystem services that provide a benefit within the property (e.g. a landscape viewpoint).
- (2) Withdrawal: the right to extract a natural resource on a property and receive an ecosystem service (e.g. harvesting timber for firewood).

- (3) Management: the right to take actions on a property that directly or indirectly alter ecosystem service provision on a property. This can affect the amount of services received by beneficiaries both within and outside the property (e.g. altering carbon storage provided due to tree clearing).
- (4) Exclusion: the right to control who can access a property. This can affect which beneficiaries can receive a benefit provided within the property (e.g. hiking).
- (5) Alienation: The right to sell, lease, or transfer any or all of the above rights for a property. This can alter which beneficiaries can receive all types of ecosystem services both within and outside the property.

From this point forward, we refer to combinations of the five property rights noted above as the property rights regime. The combination of these rights that an actor holds for a property are determined by the interplay between actors, policy-makers, legislation, and governance mechanisms (Bromley 2012; Hicks and Cinner 2014). In a sense, these rights combined with how an ecosystem service benefit is obtained define the degree to which an ecosystem service is excludable and/or rival, thus determining whether the ecosystem service in question is a public or private good, or some combination of the two, such as a toll good or common pool resource (Olson 1971; Ostrom 2010). Furthermore, this framework provides a starting point for examining how ecosystem service flow and property rights interact to enable, or restrict, actors

from obtaining ecosystem services directly. For example, actors' ability to receive flood mitigation, an ecosystem service that flows to where people are located, is more likely to be affected by management rights on properties upstream and the management of their wetlands, rather than access or withdrawal rights on the properties (Tang et al. 2020). Alternatively, the ability for actors to receive timber directly is likely to be affected by access and withdrawal rights, as obtaining this service requires being on location to harvest the timber (Gabay and Alam 2017).

Figure 1 describes our conceptual framework for how ecosystem service flows are mediated by property rights. The blue arrows show how the flow of ecosystem services is filtered through bundles of rights that determine who can obtain which services. The yellow-arrow pathway depicts how governance mechanisms also shape property rights, which then affect the policies and regulations that determine how the property is managed. Most of the attention in the literature has focused on the yellow arrows in Figure 1: how rights affect landholder natural resource management and thus the *supply* of ecosystem services. In contrast, our paper examines how rights impact those that can *receive* ecosystem services, as denoted by the blue-arrow pathway. Specifically, we conduct a detailed assessment of how rights to three ecosystem services are distributed across a landscape for four types of ecosystem service beneficiaries. We focus on the spatial distribution of the rights to frame who can (or cannot) obtain benefits from these services. Thus, this paper displays the social scaffolding for power differentials or inequalities in who manages and who relies on ecosystem services.

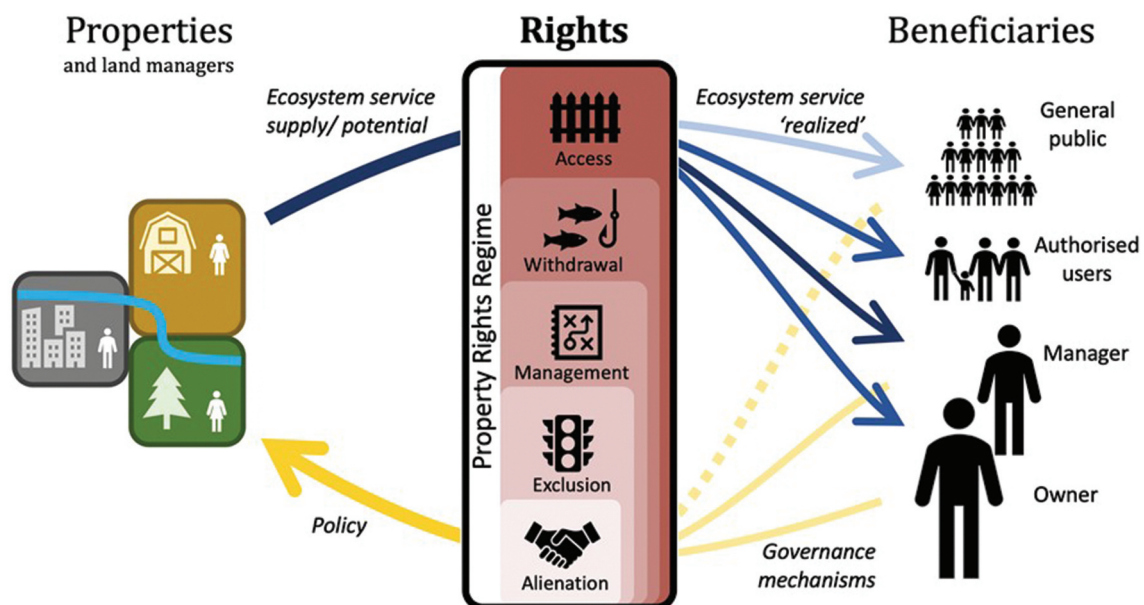


Figure 1. Conceptual framework demonstrating how various property rights influence the flow and management of ecosystem services. Right bundles combine to form property right regimes. The flow of ecosystem service from a property to beneficiaries is determined by the set of rights they hold (blue arrows). Populations enact governance mechanisms to set property rights via policy (e.g. zoning) that determine the rights and duties of property owners or managers (yellow arrows). This paper primarily focuses on how rights affect different populations' ability to obtain ecosystem services groups (blue arrows).

3. Case study

We apply our conceptual framework (Figure 1) to a case study landscape to determine how the property rights entitled under differing property rights regimes affect beneficiaries' ability to obtain ecosystem services potentially provided within the landscape.

3.1. Study area

We use the Adirondack Park in New York State, USA, as our case study (Figure 2). To protect the area's important ecosystem services, the park was originally planned to be entirely State-owned wilderness through the acquisition of all private land within the park boundary (Larkin and Beier 2014). However, growing tourism and improved access to the region increased demand for private land making it financially infeasible for the State Government to purchase it outright (Harris et al. 2012). The State instead introduced a number of unique property rights regimes to regulate how natural resources, and the ecosystem services they provide, could be used within the 2.4 million hectare park (Harris et al. 2012). The richness and uniqueness of property rights regimes in the Adirondack Park make this an ideal case to examine rights and beneficiaries, and apply our conceptual framework. We focused specifically on how the Adirondack Park's property rights regimes mediate which actors can obtain three important ecosystem services within the Park: drinking water provided by surface water, timber and recreational fishing.

3.2. Case methods

We spatially assess property rights in five steps. First, we define the ecosystem services of interest. Second, we categorise actors into four beneficiary groups based on their rights-based relationship with the landscape of interest. Thirdly, we identify the primary property rights regimes in place on each property within the landscape. We then conduct a literature review to identify which beneficiary groups can use, manage, and control each ecosystem service within each property rights regime. Finally, we map the spatial distribution of each property rights regime across the landscape to determine where a beneficiary is allowed, or not allowed, to obtain ecosystem services, and whether spatial inequalities exist among beneficiary groups, in terms of the location or size of area where each is allowed to receive ecosystem services.

3.2.1. Beneficiaries

In much of the ecosystem service literature actors are distinguished as ecosystem service managers or beneficiaries. In some cases, where an ecosystem service is enjoyed on-site, the manager and the beneficiary may be the same actor (Quinn et al. 2010). In other cases where an ecosystem service flows, managers and beneficiaries are separate (Martín-López et al. 2019). Beneficiaries, our focus in this paper, obtain an ecosystem service based on the rights they have with respect to that service.

Within our case study landscape, Adirondack Park, beneficiaries can encompass a variety of groups.

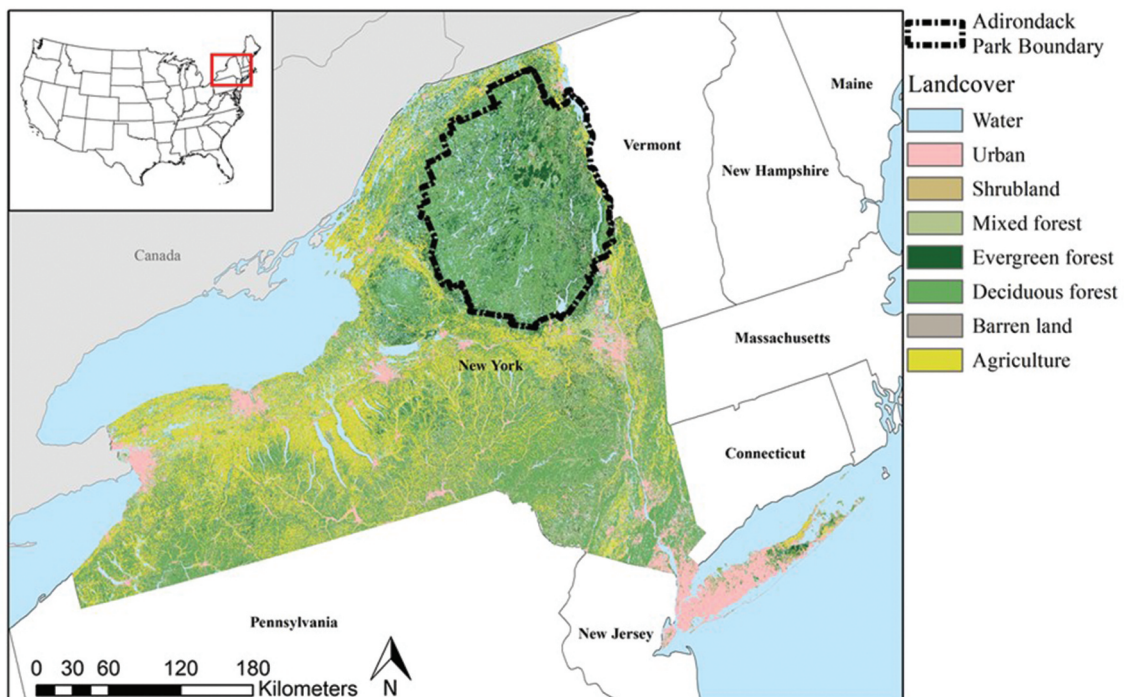


Figure 2. Location of the Adirondack Park in New York State, USA. The park contains a variety of natural resources and is an important landscape for the provisioning of multiple ecosystem services. Land cover data sourced from USGS (2019).

Therefore, following Schlager and Ostrom (1992), we categorised beneficiaries into the following groups based on their relationship to a property: owner, manager, authorised user, and general public. An owner holds the deed of the property in their name. A manager maintains a property and includes tenants. An authorised user has official permission to access a particular ecosystem service on the property, such as customers, or hikers possessing trail permits. Finally, the general public has no ownership or official authorisation for the property but may access public goods and resources. These beneficiary groups are not mutually exclusive, and, for example, a manager of a property may also be an authorized user for a particular ecosystem service on a property. These beneficiary groups describe the four main types of relationships that a person can have to a property at a given point in time.

3.2.2. Property rights regimes

Commonly, property rights regimes are classified into four categories: private, public, common and open access (Robinson et al. 2018). However, these categories can obscure differences in the bundle of property rights held within each category, and, consequently, who can obtain or manage different ecosystem services within each category (Robinson et al. 2018). For example, some private properties may allow the general public to access the property for recreation, while other private properties may not. Therefore, to understand how property rights affect the potential ecosystem services different beneficiary groups can obtain, it was necessary to further break down property rights regimes into categories that differentiate the rights associated with the use and management of multiple ecosystem services. To do this, we classify property rights regimes by the combination of their ownership entity and land use type. Property ownership (e.g. private or government) can indicate who is allowed to enter a property, who is entitled to the natural resources (and ecosystem services they provide) on a property, and whether these rights can be sold or offered to another person, providing information on each beneficiary's access, withdrawal, management, alienation and exclusion rights for a property (RRI 2018). A property's land use further indicates which natural resources are present to be managed or withdrawn to provide an ecosystem service benefit, and to some extent how a property is allowed to be used and by whom (Kärkkäinen et al. 2020). For example, a property zoned as agricultural is likely to have property rights that allow natural resources to be managed and withdrawn to provide food, an ecosystem service benefit. Together, information on property ownership and designated land use can indicate who has the five property rights, and for which ecosystem services, for a given property.

We developed a spatial dataset of all properties within the Adirondack Park (see the Supplementary

material for further details), using New York State Department of Taxation and Finance (Department of Taxation and Finance 2019) data. We grouped properties with similar types of ownership, land use, and rules authorising particular actions (from a 'Property type' variable, that describes the purpose of the property) as a proxy for property rights regimes (Schlager and Ostrom 1992).

Ownership was identified as private, local government, or State/Federal government, based on the ownership details provided in the spatial dataset. The land use of each property was determined using the 'Property type' classifications provided in the spatial dataset, and allocated to one of ten land use types (Table 1, row d). We used the 'Property type' to also identify rules or allowable actions, and grouped the properties into six 'rule' categories (Table 1, row e). Ideally, we would identify the bundle of rights associated with each ecosystem service on a property, but understandably these are not part of the record of public tax data. Ownership, land use, and rules still serve as a good proxy for understanding who has which rights to various ecosystem services on a property, and fit our illustrative purposes well. For example, private (ownership) forest (land use) implies a lack of public access to recreational benefits, whereas private (ownership) forest with easement implies public access to recreational benefits. More explicitly within our database, property type '911' refers to a forested property with 'continuing production of a merchantable forest crop', whereas property type '931' describes a forested property that is 'State-owned forest preserve' (Department of Taxation and Finance 2019).

Combining all this information, we classified the properties into ten property rights regimes: Forest preserve; Easement (other); Easement (recreation and timber); Private outdoor recreation; Public outdoor recreation; Residential; Agriculture; Commercial industry or services; Public (other); and Private (other) (Table 1, row f). These ten property rights regimes are mutually exclusive, and Table S5 (supplementary material) provides a precise mapping of how ownership, land use, and rules combine to form our regime classification.

3.2.3. Ecosystem service use under the property rights regimes

We reviewed policy documents to determine which of the five property rights (access, withdrawal, management, exclusion, and alienation) each beneficiary group (owner, manager, authorised user, general public) was entitled to under each property rights regimes, for each ecosystem service (drinking water, timber, recreational fishing). Properties categorised into the 'Other (private)' and 'Other (public)' property rights regime categories (covering 0.03% of the

Table 1. Spatial attributes collected for each property within the Adirondack Park, and how they were classified. Further information on how these attributes were classified, including look up tables, can be found in the supplementary material.

Spatial dataset Attribute	Description	Reference
a. Property Type Classification Code	Assigned to each property by the New York Department of Taxation and Finance that describe the primary use of each property for taxation purposes: <ul style="list-style-type: none"> • Agricultural properties • Residential properties • Vacant land • Commercial properties • Recreation and entertainment properties • Community services properties • Industrial properties • Public service properties • Wild, forested, conservation lands and public parks 	Department of Taxation and Finance (2019).
b. Owner type	Type of owner: <ul style="list-style-type: none"> • State or Federal Government • Local Government • Private 	See Table S1 in the Appendix for data sources.
c. Easement holder	The person or organisation that is the holder of an easement property (if applicable)	National Conservation Easement Database (2017).
d. Land use	The primary land use/ land cover of the property. Calculated based on the Property type classification code: <ul style="list-style-type: none"> • Forest • Industrial • Commercial • Recreation and entertainment • Services • Residential • Agriculture • Vacant • Easement • Other 	Department of Taxation and Finance (2019). See Table S3 in the Supplementary material for further information.
e. Rules	Rules or conditions associated with the property that affect how the property can be used. Calculated based on the Property type classification code: <ul style="list-style-type: none"> • Nature conservation • Saleable products/ business • Indoor wellbeing services • Outdoor wellbeing services • Residential • Other 	Department of Taxation and Finance (2019). See Table S4 in the Supplementary material for further information.
f. Property rights regime	The property rights regime allocated to a property. Calculated based on the Land use, Rules and owner attributes assigned to the property: <ul style="list-style-type: none"> • Agriculture: <i>Primarily used for agriculture</i> • Commercial, industry, services: <i>Provide services, materials and products (other than agricultural)</i> • Easement (other): <i>Easements not primarily used for timber harvesting or recreation</i> • Easement (timber and recreation): <i>easements used primarily for timber harvesting and recreation</i> • Forest preserve: <i>Government owned properties used for the protection of wilderness</i> • Other (private): <i>privately owned properties with no information available on land use or rules (Land use = 'other' and Rules = 'other').</i> • Other (public): <i>Government-owned properties with no information available on land use or rules (Land use = 'other' and Rules = 'other').</i> • Private outdoor recreation: <i>Privately owned and used primarily for outdoor activities by the public, either for a fee or for free.</i> • Public outdoor recreation: <i>Publicly owned and used primarily for outdoor activities by the public, for a fee or for free.</i> • Residential: <i>Used primarily for housing (non-commercial).</i> • Unknown: <i>properties that were not classified due to lack of information.</i> 	See Table S5 in the Supplementary material for further information.

Adirondack Park) were removed from this analysis, due to minimal information available on the property rights present on these properties (Table 1, row f).

We screened all legislation and management plans that outline restrictions and regulations associated with the use, management and control of drinking water, timber and recreational fishing within the Adirondack Park (see Tables S6-S8 in the Supplementary material for a full list of policy documents reviewed). We also consulted staff from the New York State Department of Environment and Conservation (S. Reynolds. Personal communication, 11 July 2019) and the Adirondack Park Agency (R. Weber. Personal communication, 5 July 2019) for property rights information we could not source

from the literature. These Government agencies are responsible for regulating natural resource use within the Adirondack Park. For each property rights regime (Table 1, row f), we recorded whether each beneficiary type had unconditional, conditional, or no access, withdrawal, management, exclusion and alienation rights for each ecosystem service (Table 2). An 'unconditional' right was defined as having a property right with no restrictions attached to it. A 'conditional' right was defined as having a property right but with conditions, such as the right to withdraw only to a specified amount. A 'no' right was defined as not being entitled to a given property right. For drinking water, we focused solely on property rights associated with drinking water

Table 2. Information coded from the literature to determine, for each property rights regime, which of the five property rights each beneficiary (owner, manager, authorised user, and general public) have for each ecosystem service.

	Ecosystem services		
	Drinking water	Timber	Recreational fishing
Access rights	Yes: Can enter the property. Conditional: Can enter a property, with restrictions (e.g. frequency). No: Cannot enter a property.	Yes: Can enter the property. Conditional: Can enter a property, with restrictions (e.g. frequency). No: Cannot enter a property	Yes: Can enter the property. Conditional: Can enter a property, with restrictions (e.g. frequency). No: Cannot enter a property
Withdraw rights	Yes: Can extract water from a surface waterbody for drinking water. Conditional: Can extract water from a surface waterbody for drinking, with restrictions (e.g. amount that can be withdrawn). No: Cannot extract water from a surface waterbody for drinking water.	Yes: Can cut down trees for timber. Conditional: Can cut down trees for timber, with restrictions (e.g. limit on the number of trees that can be harvested). No: Cannot cut down trees for timber.	Yes: Can recreationally fish. Conditional: Can recreationally fish on a property, with restrictions (e.g. the amount of fish that can be caught) No: Cannot recreationally fish.
Management rights	Yes: Can manage surface waterbodies for drinking water (e.g. installing pipes and pumps). Conditional: Can manage surface waterbodies for drinking water, with restrictions (e.g. restrictions on when pumps or pipes can be installed, and where). No: Cannot manage surface waterbodies for drinking water.	Yes: Can manage trees that can provide timber (e.g. can choose the harvesting regime). Conditional: Can manage trees that can provide timber, with restrictions (e.g. only partially able to choose the harvesting regime). No: Cannot manage trees that can provide timber.	Yes: Can manage recreational fishing on a property (e.g. stocking fish, restrict fishing in areas). Conditional: Can manage recreational fishing, with restrictions (e.g. can prevent fishing in areas, but cannot stock fish). No: Cannot manage recreational fishing.
Exclusion rights	Yes: Can control who can access the property. Conditional: Can control who can access the property with restrictions (such as can control when people enter the property, but not who can enter the property). No: Cannot control who can access the property.	Yes: Can control who can access the property. Conditional: Can control who can access the property with restrictions (such as can control when people enter the property, but not who can enter the property). No: Cannot control who can access the property.	Yes: Can control who can access the property. Conditional: Can control who can access the property with restrictions (such as can control when people enter the property, but not who can enter the property). No: Cannot control who can access the property.
Alienation rights	Yes: Can sell, lease, or transfer any or all of the above rights for a property. Conditional: Can sell, lease, or transfer any or all of the above rights for a property, with restrictions (e.g. can sell or lease only some management rights). No: Cannot sell, lease, or transfer any of the above rights for a property	Yes: Can sell, lease, or transfer any or all of the above rights for a property. Conditional: Can sell, lease, or transfer any or all of the above rights for a property, with restrictions (e.g. can sell or lease only some management rights). No: Cannot sell, lease, or transfer any of the above rights for a property	Yes: Can sell, lease, or transfer any or all of the above rights for a property. Conditional: Can sell, lease, or transfer any or all of the above rights for a property, with restrictions (e.g. can sell or lease only some management rights). No: Cannot sell, lease, or transfer any of the above rights for a property

provided by surface waterbodies, such as lakes, rivers and reservoirs, and not groundwater because surface water is a main source of drinking water for the residents of the Adirondack Park, as outlined in the New York State drinking water reports (New York State 2021).

3.2.4. Mapping distribution property rights regimes and beneficiaries

To determine how property rights regimes affect the spatial area available to each beneficiary group to obtain ecosystem services across the Adirondack Park, we mapped the property rights regime categories to the tax parcel spatial dataset (Department of Taxation and Finance 2019). This produced a final spatial dataset showing the location of every property rights regime, and the property rights each beneficiary is entitled to on these properties, for each ecosystem service. We then determined the locations where each beneficiary is allowed to obtain each ecosystem service. In this study we assume that each property has the potential to provide any of the three ecosystem services, based on the following land parcel

features. For drinking water, we focus on drinking water sourced from surface water only and therefore assume any property has the potential to provide this service, as it can be provided through both rainfall and waterbodies that are contained within or partly within the property. Recreational fishing is potentially available on any property where a waterbody is partly or fully contained within the property. Finally, we assume timber has the potential to be provided on all land parcels, as every land parcel has the *potential* to provide trees, through tree planting. We did not account for the magnitude or ‘quality’ of supply on each property to maintain a focus on the institutions that determine ecosystem service beneficiaries.

We estimated the number of potential beneficiaries by identifying which beneficiary groups had access and withdrawal rights on each property for each service, and calculating the number of people within each of those groups. First, we calculated the number of owners and managers listed for each property provided in the spatial dataset. We then estimated the number of general public beneficiaries

based on Adirondack Park population and tourist statistics. Due to the lack of data available on authorised users for drinking water and timber, we only calculate the number of potential authorised users for recreational fishing, based on the number of people possessing a New York State fishing permit. Further details on beneficiary calculations, and data sources, are provided in the Supplementary material (Table S2).

As drinking water and recreational fishing are both potentially provided on any property with a waterbody that may share their shoreline with multiple properties, it is likely that the properties right regimes in place on these properties could influence the ability for other people to obtain these ecosystem services from these shared waterbodies. To examine this, we identified all properties that included shoreline of a waterbody or water course shared with other properties. We then identified the property rights regimes allocated to each of these properties to assess how they potentially affect the ecosystem services that other beneficiaries can gain in other locations along the waterbodies.

Properties that we were unable to determine the property rights regime for, due to lack of data, were not assessed (0.032% of the Adirondack Park area). All data analysis was conducted using ArcGIS 10.5.1 (ESRI 2011) and R statistical software (R Core Team 2019).

4. Results

4.1. Ecosystem service beneficiaries

Beneficiaries' bundle of property rights for each ecosystem service varies across the property rights regimes (Figure 4). See tables S6-8 for further details on the bundles of rights of each beneficiary group.

4.1.1. Property owner

Owners have the greatest number of rights to receive or manage each ecosystem service, across all property rights regimes, as one might expect from private ownership (Figure 3). For all three ecosystem services, owners have the right to enter all property rights regimes, which is necessary to be able to access any of the three ecosystem services. Owners have the right to withdraw natural resources to obtain drinking water, timber, and recreational fishing on all property rights regimes, though we still see that full property owner's rights are restricted for the withdrawal and management of some resources. The right to withdraw drinking water is conditional on obtaining a permit, except on agricultural properties where no permit is required (New York State Senate 2019). Owners can harvest up to 25 acres of timber on all property rights regimes, except forest preserve where no timber harvesting is allowed (Department of

Environmental Conservation 2019a). Owners can withdraw fish on all properties, though a permit is required on forest preserve properties (Department of Environmental Conservation 2019b).

Owners generally have management rights for the natural resources that provide all three ecosystem services on all property rights regimes, but again these are subject to some conditions. For drinking water, property owners can manage water bodies unconditionally on forest preserve properties, but on all other properties management cannot negatively affect downstream properties. For timber, owners have the unconditional right to manage trees to provide timber on all properties except forest preserves. For recreational fishing, owners have the right to manage fish stocks for recreational purposes unconditionally on all properties except for forest preserves. Owners' exclusion and alienation rights were mostly similar for drinking water and recreational fishing across the property rights regimes with unrestricted rights, but conditional exclusion and alienation rights for forest preserves and both easement property rights regimes (where only minor changes can be made).

4.1.2. Manager

Managers of properties are those who actively participate in controlling or managing land, but do not own the land. Managers have the second greatest number of property rights across the property rights regimes, after owners (Figure 3). Access rights across all services were the same as for owners. Withdrawal rights for managers were the same as owners for both timber and recreational fishing but differed for drinking water. While owners have unconditional withdrawal rights for drinking water on agricultural properties, managers have conditional rights, dependant on the contract with the owner. Managers, almost by definition, have some management rights, though we find they have fewer than owners. For example, managers do not have the right to manage natural resources providing drinking water or timber on agricultural and residential properties, as well as timber on forest preserve properties. For the remaining types of properties, management rights are conditional on the contract or permit. For recreational fishing, managers cannot manage resources for recreational fishing on commercial, industry services properties, as well as private outdoor recreation and residential properties. Management is conditional on the remaining property rights regimes. Unlike owners, managers have no exclusion or alienation rights on any property rights regime for drinking water and timber. Managers do have exclusion rights for recreational fishing on forest preserve, easement (recreation and timber) and public outdoor recreation properties, but no alienation rights.

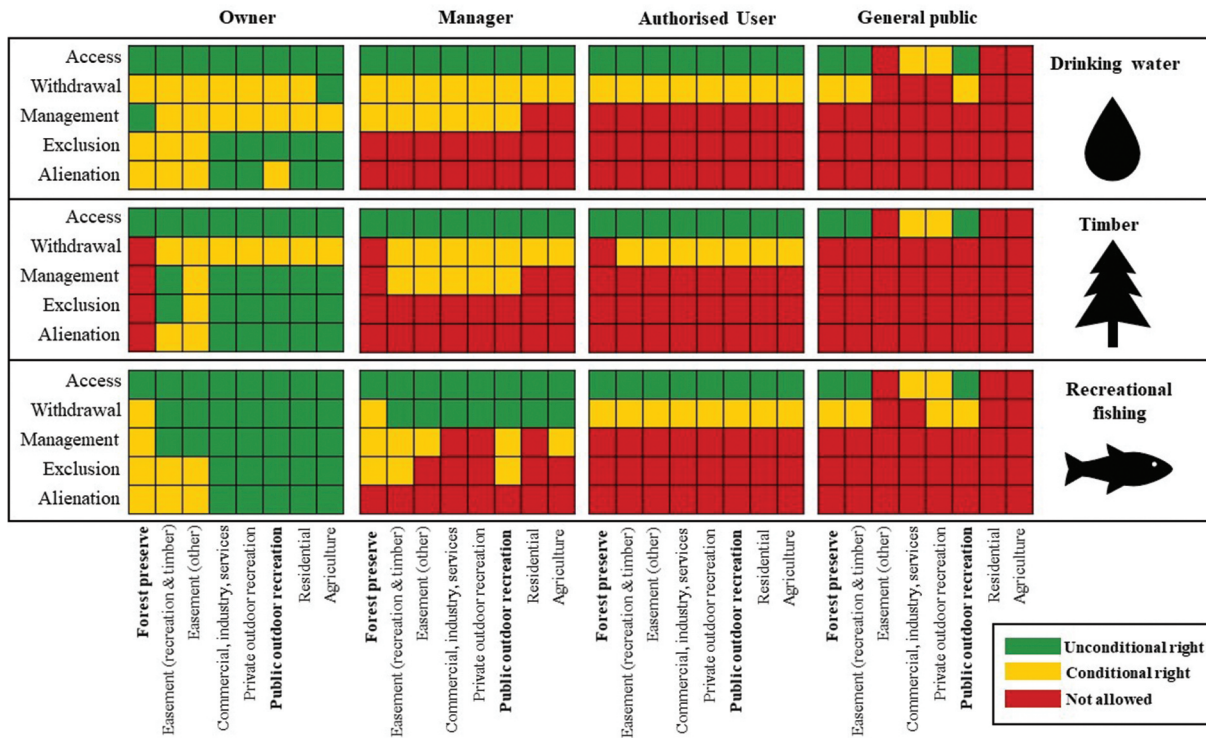


Figure 3. Property rights allocated to each beneficiary for each ecosystem service, on each property rights regime within the Adirondack Park. Green indicates that the beneficiary can exercise that right freely. Yellow indicates that a beneficiary has that right but there are some restrictions attached to it. Red indicates a beneficiary does not have that property right. Property rights regimes in bold denote publicly owned properties (easements are regarded as privately owned here, but are often regarded as a hybrid between public and privately owned). Further descriptions for each of these rights are provided in Tables S5-7 in the Supplementary material. Note that two property rights regimes ('Other (private)' and 'Other (Public)') were not included in this analysis due to lack of data.

4.1.3. Authorised user

Authorised users, such as permit holders or customers, have fewer rights for each ecosystem services across all property rights regimes, compared to owners and managers (Figure 3). Authorised users have the same access rights as owners and managers. However, an authorised user has only conditional withdrawal rights, conditional on a permit or the contract in place with the owner, for all three ecosystem services, across all property rights regimes except for forest preserve (where the authorised user – like the owner and manager – has no withdrawal rights). Finally, authorised users have no management, exclusion nor alienation rights within any property rights regime, for any ecosystem service.

4.1.4. General public

Generally, the broad members of the public have the fewest property rights of any beneficiary group for all property rights regimes (Figure 3). The general public has the right to access forest preserve, easements (recreation and timber), and public outdoor recreation properties, and conditional access rights for private outdoor recreation and commercial, industry, services properties, provided they are customers or clients. Withdrawal rights are mixed. The general public cannot withdraw timber from any property rights regimes,

however, they do have withdrawal rights for drinking water and recreational fishing, conditional on permits, for forest preserves, easements (recreation and timber) and public outdoor recreation properties. Furthermore, the general public has withdrawal rights only for drinking water on private outdoor recreation properties, dependant on permits. Finally, the public has no management, exclusion or alienation rights on any property rights regime for any ecosystem service.

4.2. Spatial distribution of rights to ecosystem services

The distribution of the ten property rights regime categories that make up the Adirondack Park, as identified through tax records, are shown in Figure 4. Forest preserves – State Government-owned properties used for wilderness and conservation purposes – cover the largest area (1,088,231 ha, 49.07%), followed by residential properties (417,017 ha, 18.81%). The spatial distribution of the property rights regimes across the Adirondack Park affected the amount of area within the park that each beneficiary can withdraw natural resources from to receive ecosystem service benefits. Owners and managers of 144,466 properties, with an average property size of 15.35 ha, can either conditionally or unconditionally withdraw water and

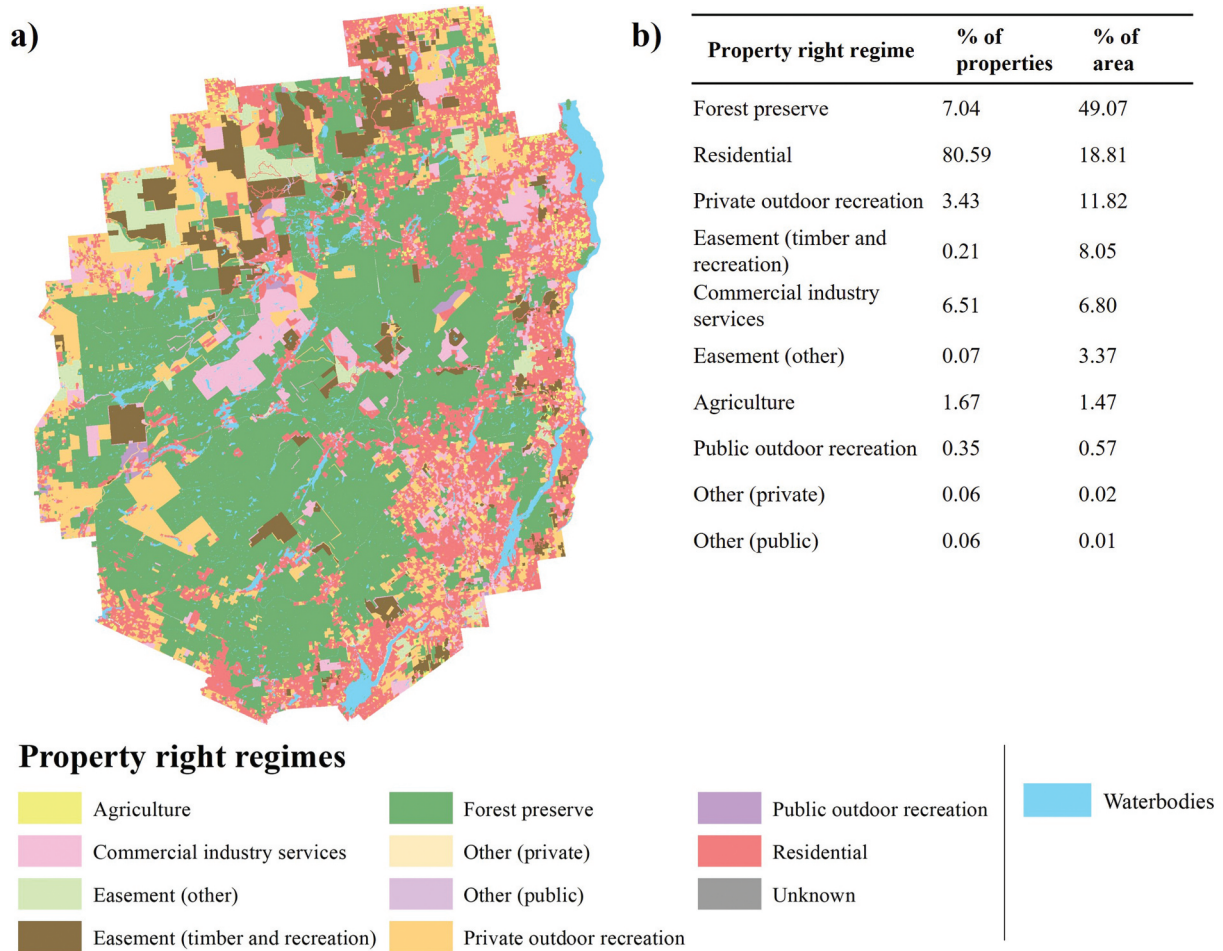


Figure 4. The property rights regime categories for the Adirondack Park, showing (a) the location of each property rights regime, and (b) the proportion of area and total properties within the Adirondack Park within each property rights regime category.

recreationally fish from surface waterbodies located on their property (Figure 5). Owner or managers of 134,288 properties, with an average property size of 8.4 ha, can conditionally harvest timber on their property. Authorised users for drinking water and recreational fishing can conditionally withdraw water or recreationally fish on any property they have permission for, a potential 144,466 properties, or total area of 2,216,864 ha (99% of the total park area). For timber, there are potentially 134,288 properties (total area 1,128,632.90 ha, 51%) that an authorised user may have permission to conditionally harvest timber (Figure 5). The general public can conditionally withdraw water on 10,986 properties (total area of 1,279,441.64 ha, 58%), and conditionally recreationally fish on 15,947 properties (total area of 1,541,554.19 ha, 70%). The general public cannot withdraw timber on any property within the Adirondack Park.

4.3. Property rights can induce potential externalities for shared resources

Due to ecosystem service flow, the ability for potential beneficiaries to withdraw water and to recreationally fish on properties is impacted by the

management, exclusion and alienation rights of upstream actors or those with properties on the same waterbody. As shown in Figure 6, the majority of shoreline (46.85%) of water bodies shared by multiple properties is located within forest preserve properties. Under this property rights regime, forest preserve owners have unconditional management rights for water and conditional management rights for recreational fishing, as well as unconditional exclusion and alienation rights for both services along this shoreline. Additionally, 25.63% of the total shoreline of waterbodies that are shared by multiple properties is located within residential properties, where owners have unconditional management rights for recreational fishing and conditional management rights for water. Further, owners have unconditional exclusion and alienation rights for both services on residential properties. This gives owners within these properties the right to manage and control these ecosystem services in such a way that it potentially impacts the ecosystem services that potential beneficiaries on other properties that share these waterbodies can receive, such as the extraction of surface water to provide drinking water.

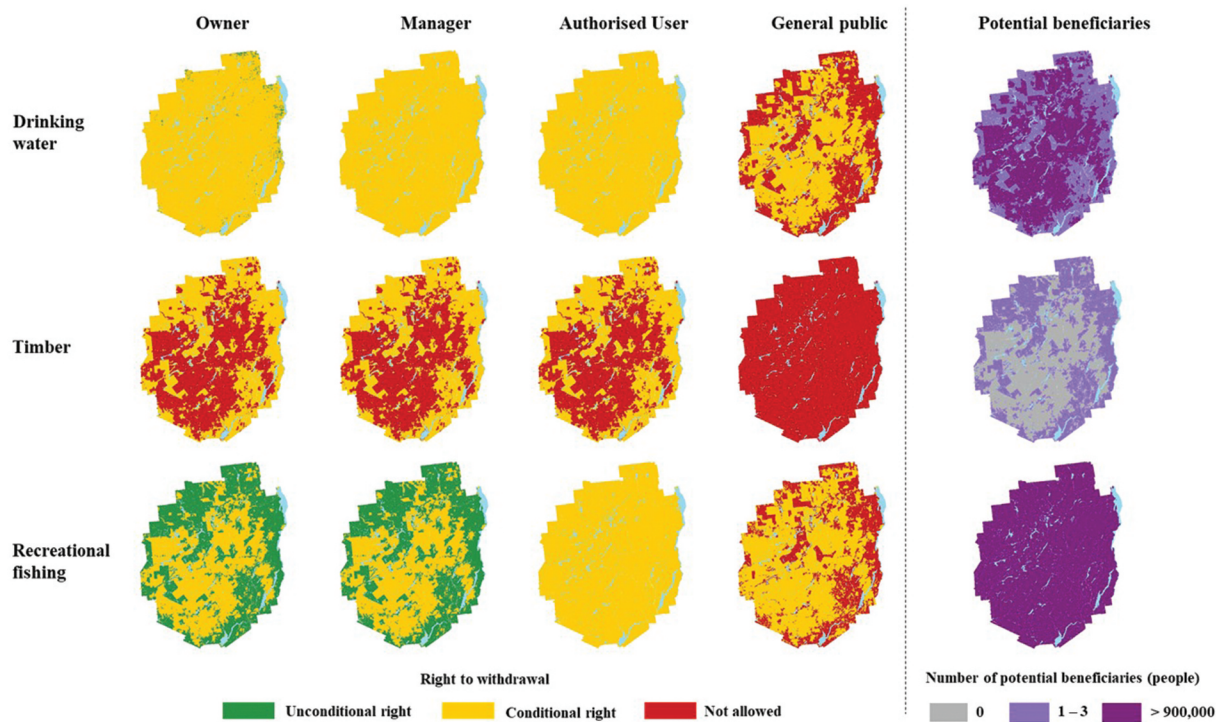


Figure 5. The location of properties where each beneficiary group have the right to withdrawal each ecosystem service within the Adirondack Park based on the property rights regimes in place, and the estimate number of people who can benefit from each services on each land parcels, based on the estimate number of people within each beneficiary group. The estimate of beneficiaries calculated for drinking water and timber do not include the number of authorised users.

5. Discussion

Once ecosystem services are supplied on the landscape, property rights determine who can obtain them, how much, and where. Our results show that there is highly unequal use and control rights over potential ecosystem services within the Adirondack Park, with a single group of actors, the property owners, controlling much of the other beneficiaries' ability to obtain ecosystem services potentially provided by the landscape. In a region where private property is the dominant form of land allocation, perhaps this is to be expected. Still, there is a growing acknowledgement that it is necessary to understand the governance mechanisms that affect people's ability to obtain ecosystem services (Schröter et al. 2017). Our methodological framework and results demonstrate that property rights play a central role in determining how ecosystem services are exploited by and excluded from certain populations, with important implications for the management of ecosystem services and well-being of all populations. This is summarised in three main points that emerge from our results regarding the role of property rights in determining how much of an ecosystem service can be obtained, by whom and where, and the role of power relations in determining beneficiaries.

How much of an ecosystem service can be obtained?

Our results demonstrate that property rights regimes influence the amount of ecosystem services that beneficiaries can obtain from a natural resource. For

example, within the Adirondack Park, none of the four beneficiary groups can harvest timber on forest preserve properties, but can harvest 25 acres on other properties. However, as forest preserve properties cover almost 50% of the landscape and contain large areas of forest, the amount of timber that beneficiaries can potentially harvested is severely restricted due to the property rights in place (Harris et al. 2012). These findings support previous studies demonstrating the role of land tenure in access to natural resources (RRI 2018; Ban et al. 2015), and show that property rights play a powerful role in mediating the amount of ecosystem services that are allowed to be obtained from natural resources.

Who could obtain an ecosystem service, and where?

Within the Adirondack Park, property owners had withdrawal rights on the most property rights regimes for all three ecosystems services, while the general public had the least with conditional withdrawal rights for drinking water and recreational fishing on three property rights regimes. However, the total area available to the general public to withdraw water and recreationally fish on these three property rights regimes is larger than the average sized property available to an owner. But, importantly, though the owner only had additional property rights on their parcel of land, they are regarded as the general public on other properties, meaning they had overall greater access to ecosystem services across the park than someone who is not a property owner. These findings

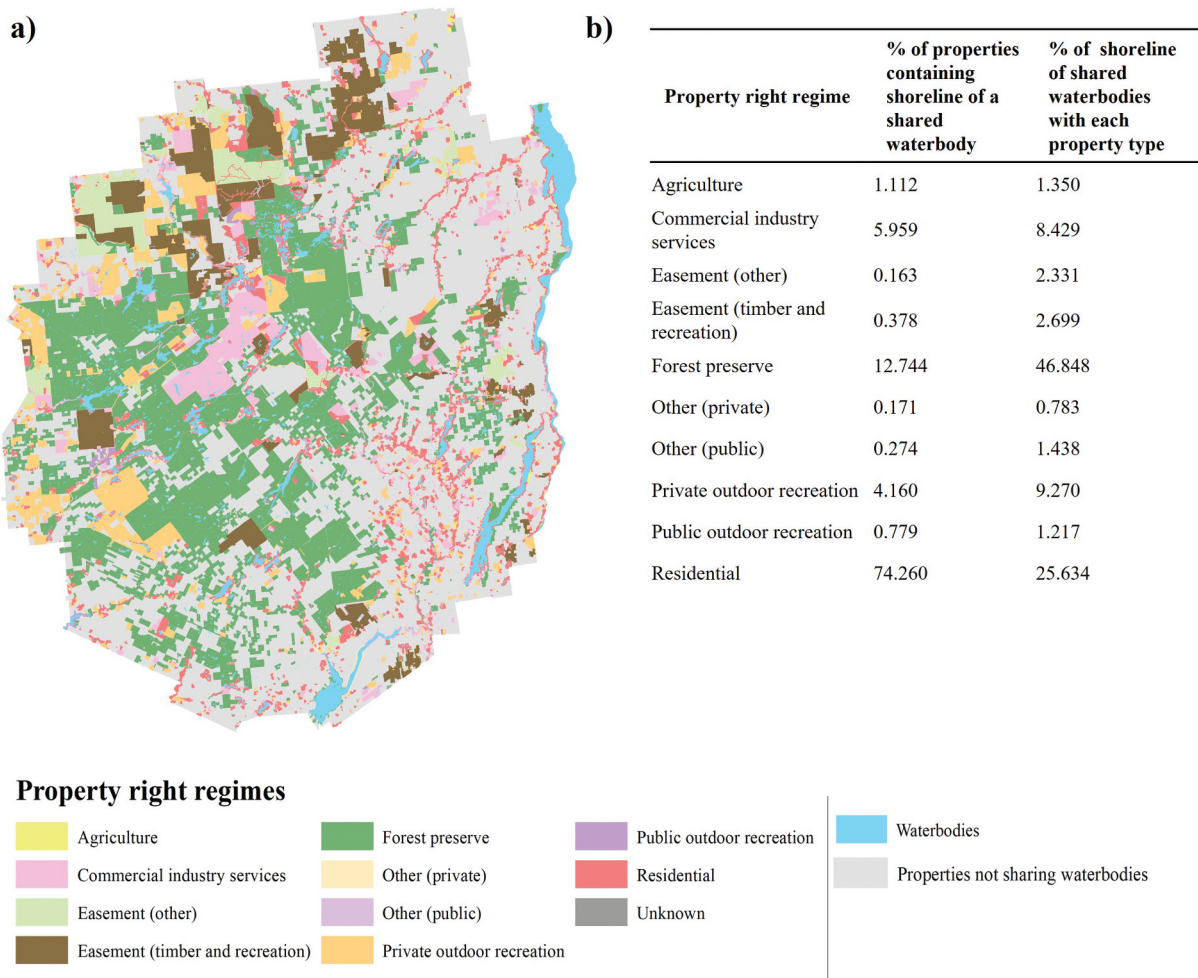


Figure 6. The property types that contain shoreline of waterbodies that are shared by multiple properties showing (a) the location of each property type, and (b) the proportion of each shared water resource's border that has a common border with each property type.

suggest property rights can exacerbate inequalities among different populations, as some people may have the right to obtain a greater variety of ecosystem services from a larger area or from locations with a greater supply of ecosystem services, defining winners and losers in terms of who can obtain ecosystem services (Benra and Nahuelhual 2019). However, if leveraged correctly, property rights can also regulate the equitable distribution of ecosystem services among beneficiaries. For example, to increase the provisioning of ecosystem services across landscapes, identifying which land parcels have property rights regimes that allow a greater number of people to obtain the target ecosystem services within them can ensure management actions are allocated within these parcels to ensure a greater number of beneficiaries, such as restocking fish in waterbodies to increase the amount of fish (an ecosystem service) available (Felipe-Lucia et al. 2015). If managers want to avoid exacerbating inequality gaps between different beneficiary groups, management that aims to increase ecosystem service provisioning must consider the role property rights will play in determining who will benefit from increased ecosystem service provisioning (Villamagna et al. 2017).

How do power relations affect the ability to obtain ecosystem services? In the Adirondack Park, many owners of properties containing the shorelines of shared waterbodies had management and alienation rights for drinking water and recreational fishing. This allows these owners to make changes to the shared waterbody, within the borders of their properties, that could affect the ability of other potential beneficiaries to extract water and fish from this shared resource. For example, an owner could reduce the amount of water or fish available not only for themselves but also for other users of this shared resource (Atapattu and Kodituwakku 2009). Therefore, power relations surrounding shared natural resources and the flow of ecosystem services can exacerbate inequalities in terms of the ecosystem services available to different actors (Felipe-Lucia et al. 2015; Barbés-Blázquez et al. 2016). Our results highlight that, if not carefully regulated, property rights could reduce equitable distribution of ecosystem services that are regarded as rival goods among populations, with actors that have controls rights able to obtain more ecosystem services at the cost of other actors.

The quantity of an ecosystem service that flows to a person is often determined by the amount (or supply) of the ecosystem service present, and the social-cultural factors that influence the person's ability to receive a benefit from the service, such as values, education and socio-economic status (Sikor 2013; Hicks and Cinner 2014). Our results demonstrate that another driver also mediates ecosystem service flow, with important implications for ecosystem service use: property rights. By considering the property rights in place on land parcels across landscapes, alongside ecosystem service quantity and social-cultural characteristics of the potential beneficiaries, it is possible to determine where managing ecosystem services to increase supply will benefit the greatest number of people, in terms of who is able to and is allowed to obtain ecosystem services from those locations, and how much. Integrating property rights into ecosystem service management and policy will require combining our framework with models of ecosystem service supply and socio-cultural variables, which would allow for the exploration of how the distribution of ecosystem service benefits among different beneficiaries shifts under differing management scenarios across landscapes, and indicating which scenarios benefit which beneficiary groups the most.

While our case highlights common ways property rights allow or prevent beneficiaries from receiving ecosystem services, the Adirondack Park is a unique case study, and other landscapes may differ in the ways in which these pathways operate (e.g. Sikor et al. 2017). For example, in places where property rights are more insecure, or governance is weaker, changes in the status quo may lead to conflicts that undermine efforts to change the distribution of services among different actors (Costello and Grainger 2018; Robinson et al. 2018). Furthermore, our case study focuses on place-based ecosystem services, where a person must be present on the property to obtain an ecosystem service. Other ecosystem services, which can be benefitted from without needing to be present on the property, such as air quality regulation and water quality regulation (Burkhard et al. 2014), will likely behave differently under differing property rights regimes. Further research into the implications of different property rights regimes, and ecosystem services, on beneficiaries might further elucidate whether property rights could be an effective mechanism to mediate ecosystem service delivery in other situations.

6. Conclusion

Understanding the role of property rights in mediating who can or cannot obtain ecosystem services is vital for assessing the distribution of ecosystem services

among populations within landscapes (Hicks and Cinner 2014). Our study demonstrates that property rights regimes play a fundamental role in governing the flow of ecosystem services among different actors, with some actors, particularly property owners, having greater control and usage rights for ecosystem services than other actors. This suggests that property rights regimes can exacerbate inequalities in obtaining ecosystem services, determining winners and losers. But property rights can also potentially ameliorate these inequalities by guiding more equitable management of ecosystem services across landscapes.

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