Three decades of forest harvesting along a suburban–rural continuum

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Abstract. Timber harvest is an important ecological disturbance that influences species composition, understory conditions, stand structure and growth, and carbon dynamics. Regional variation in harvest regimes and the associated ecological consequences are linked to social and biophysical attributes of the landscape. We analyzed three decades of change in commercial timber harvesting on all private and public forest throughout 328 towns in Massachusetts (USA). We quantified changes in harvest activity over time and estimated probability of harvest occurrence and proportion of a town's harvest as functions of biophysical and social settings. We found little evidence of any temporal trends in harvest activity at the state or town scale. Across the suburban–rural interface, the probability of harvest occurrence on private land was consistently a function of the proportion of a town's land in forest and the distance to the urban center (Boston). The proportion of private land in a town subject to harvest was negatively related to a town's median household income. There was a significant difference in the proportion of private forest harvested in suburban vs. rural towns. The proportion of public forest subject to harvests was not related to any of the variables we examined. Total statewide estimates of commercial timber that fail to account for the suburban–rural transition may overestimate available or potential volume. Ecologically, the timber harvest disturbance regime in landscapes dominated by private ownership is strongly influenced by socioeconomic factors such as affluence and proximity to urban development, unlike other forms of natural disturbance typical of the region (e.g., wind).

Key words: coupled natural and human systems; disturbance ecology; private land; socioecological system; suburban–rural interface; timber harvest.

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INTRODUCTION

Forest ownership across the USA is a complex mix of public, private commercial, and private non-industrial, with the largest single category being private non-corporate (also often referred to as family forest). Family forests dominate the eastern states where there is a paucity of federal ownership (Butler and Ma 2011). The management of forests, especially the harvest behavior,

can have a significant effect on the corresponding structure and composition of the forest. Indeed, in northeastern U.S. forests, harvest is a larger cause of mature tree mortality than all other causes combined (Canham et al. 2013). Like other important agents of forest disturbance, the modern harvest regime varies with respect to forest composition and biomass, and produces stands of varying age structure and species composition. But unlike many "natural" disturbance

regimes, harvest regimes vary by both biophysical and social drivers (Thompson et al. 2017). Harvest behavior on public (i.e., federal, state, or municipally owned) forest may be quite different, depending on agency mandate, management objectives, and the complex decision-making process. We hypothesize that patterns and drivers of harvesting vary along social, ownership, and biophysical gradients. An improved understanding of these gradients will contribute to a stronger understanding of contemporary forest dynamics.

We quantified the extent and nature of harvest over 30 yr in the State of Massachusetts, spanning a dynamic suburban–rural interface. Documenting the historical patterns of harvesting over such large spatial and temporal extents enabled us to explore parallel and important phenomena: (1) timber harvest as an important ecological disturbance regime and (2) timber harvest as an important land-use regime and provisioning ecosystem service. The goal of this study was to understand how these roles have changed over 30 yr across rural and suburbanizing landscapes.

Background

McDonald et al. (2006) studied commercial harvesting in Massachusetts and determined that road density and median home price were the most important predictors of timber harvest probability between 1983 and 2003. They concluded that "Current forest management regimes are determined largely by the economic influence of nearby urban centers," implying the negative impact on harvest of development, and the importance of forests for their amenity and aesthetic values rather than wood products. This is not unique to Massachusetts. Wear et al. (1999) estimated that the probability of a commercial timber sale in Virginia was reduced to zero once population density approaches 58 people/km^2. Munn et al. (2002) studied the effect of various suburban attributes on harvest probability in the south central region of the USA (Alabama, Arkansas, Louisiana, Mississippi, eastern Oklahoma, Tennessee, and eastern Texas) and concluded that "Harvesting rates decreased by as much as 19% as population densities increased or distance to urban areas decreased. The results indicated that active forest management is curtailed far beyond the urban boundary." In western Oregon, Kline et al. (2004) explored harvest patterns in the wildland–urban interface and identified that building density on non-federal land had a significant and negative effect on the probability of pre-commercial thinning, but not on commercial harvest. Physical attributes of the landscape, such as roads and homes, appear to consistently influence the likelihood of harvest in these rural–suburban interfaces.

The social context of a forest landscape can significantly alter the harvest regime. Across the northeastern United States, the probability of harvest on family forest is 25% less than on corporate-owned lands, but twice as much as on public land (Thompson et al. 2017). Butler et al. (2010) investigated what they referred to as the social availability of timber in the same region and estimated a reduction factor for the total potential timber volume, based on attributes such as population density, parcel size, and landowner attitudes toward harvest. They concluded that the total potential available timber volume in Massachusetts could be reduced by as much as 67% based on these social factors, and 59.6% in the broader 20-state region. "Woodland neglect" or "under-management" was described as an explicit social practice in the United Kingdom (Dandy 2016), whereby private owners intentionally do not to manage their timber. Similarly, loggers and timber procurement managers were surveyed in northern New England and queried about the potential effects of sprawl development on timber availability (Egan et al. 2007). "Results suggested concern about sprawl among approximately one-half of the logger respondents in the region, particularly in New Hampshire, where 60% of respondents indicated that there will be less logging in their area in 10 yr because of sprawl."

Bliss (2003) argued that family forests are threatened by parcelization and fragmentation at the urban fringe, and this issue is greater than a simple matter of economics or management of a parcel or woodlot. "The role of family forests in the wider context of landscape, culture, and rural economy" warrants attention (Bliss 2003). Decline in the traditional approaches to forest management on family forest lands results in less available timber to contribute to a local economy and changes in ownership attitudes can lead to closing of traditional access by the public for recreation (Stein et al. 2009).

D'Amato et al. (2010) also studied the management costs and returns of individual family forest ownership in rural western Massachusetts, far from the suburbanizing fringe. They simulated growth and yield of stands, used real stumpage prices and property tax costs of management, and estimated that conventional forest management would be insufficient to offset ownership costs, unless properties were enrolled in a current-use property tax program or the development rights to the property had been eased. The notion that timber could "pay its way" for landowners did not hold, without programmatic intervention or subsidies. In the vast majority of cases including suburban forest in eastern Massachusetts, harvest activity is not affected by stumpage prices, but there is some evidence that in rural areas stumpage does affect aggregate harvest practices (Kittredge and Thompson 2016). Loggers in Massachusetts were surveyed, asking about the minimum sale that they would agree to operate, and the mean response was 2.1 ha (5.3 acres) or 59.5 m^3 (17.1 Mbf; Kittredge et al. 1996). This response was mediated, however, by the relative quality of the timber. Ownerships with little high-quality timber (that had been previously high-graded) were considered inoperable. Many additional social factors have also been linked to the decision to harvest on private land, including the owner's age, income, and educational attainment, generational transfer, and whether or not the owner lives on the land (Silver et al. 2015, Thompson et al. 2017).

Smaller ownerships in the suburbanizing areas can mean more neighbors and visibility. Forest management in the suburban fringe could be further complicated by concerned neighbors and local officials. The solution to this could be more communication and proactive outreach to those concerned, but this comes at an additional cost to the private consulting forester (or the landowner client) and can represent additional constraints beyond merely timber quality and quantity (e.g., Edwards and Bliss 2003, Shelby et al. 2004). Colgan et al. (2014) referred to this notion of "forests in the transition zone," "where forests and people strongly intermingle," and argued the importance of these forests for the wealth of ecosystem service benefits made available to large numbers of people. They observed, however, that these forests have been "relatively overlooked in terms of research and management."

MATERIALS AND METHODS

Study area

Situated on the northeastern coast of the United States, Massachusetts is densely populated and densely forested, making it well suited to studies of coupled human and natural systems (Fig. 1). Roughly two-thirds of its more than 1.2 million hectares of forest (66.9% of the state) is privately held. Most private forest (84.3%) is in the private, non-corporate category (i.e., private lands not owned by corporate interests, including individuals, Native American lands, unincorporated partnerships, clubs, and lands leased by corporate interests), while the balance is considered private corporate (i.e., forest land that is administered by entities that are legally incorporated, Smith et al. 2009). State agencies are responsible for more than half of the public land (57.7%), while county and municipal forest comprise 36.4%, and federal forest is the remaining small fraction (Oswalt et al. 2014).

Families and individuals are the predominant owners of private non-corporate lands (also commonly referred to as non-industrial private or private woodlands). Private ownerships are numerous and small (an estimated 27,000 ownerships >4 ha or 10 acres; mean ownership of 15.5 ha; Butler and Barnett 2014). As elsewhere in the United States, Massachusetts forest owners place high priority on appreciative and non-consumptive benefits and are well educated, and harvest revenue is not considered an important fraction of their overall income (Belin et al. 2005, Butler 2008, Rickenbach and Kittredge 2009). Between these prevalent non-consumptive ownership goals and the lack of a critical mass of industrial forest, the sawmill industry is small (e.g., 30 sawmills in 2006; De la Cretaz et al. 2010) and there are no pulp mills.

Harvest data

We analyzed a unique database that describes all public and private commercial timber sales in Massachusetts ($n = 20{,}544$) between 1984 and 2013. Commercial harvest is regulated through the state's Forest Cutting Practices Act, which dictates that a Forest Cutting Plan (FCP) be submitted for each timber sale >87 m^3 (25,000 board feet, Mbf). This regulation only applies to operations that result in a property that remains in forest land use. Changes in land use (e.g., forest conversion to developed use) are not documented by FCPs.
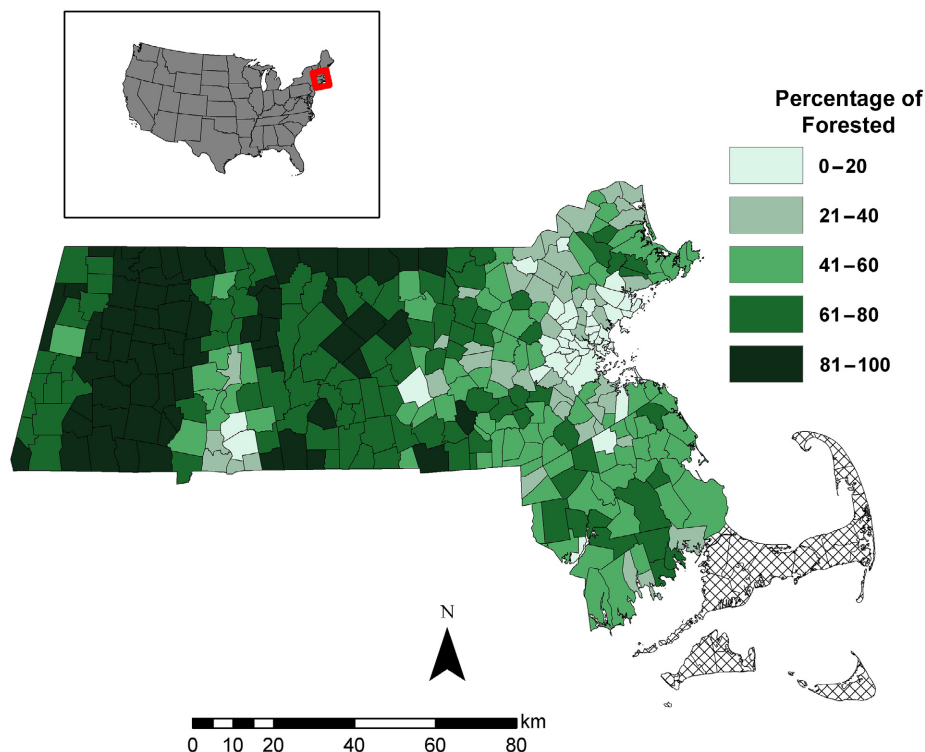
Fig. 1. Massachusetts towns by percent forest land cover, based on the 2011 National Land Cover Database. The hashed area was excluded from the study (see text for details).

These regulations are overseen by the state's Bureau of Forestry, and submitted FCPs are reviewed by county foresters and approved if found in compliance with the regulations. Estimates of area treated and volume removed are provided, but not confirmed by the county forester, unless they appear to be excessively inaccurate. Since these data are regulatory, and not gathered or compiled for research purposes, they may not represent the absolute total of harvest activity, but Massachusetts is a small, densely populated state, and unregulated logging is easily noticed. To date, these data have been used to explore patterns in harvest in several ways (Kittredge et al. 2003, McDonald et al. 2006, 2008, Thompson et al. 2011, Blumstein and Thompson 2015, Kittredge and Thompson 2016). This study expands on previous efforts, considering a longer time period and the dual phenomena of harvest as an ecological disturbance and as a source of timber.

Massachusetts is divided into a political and geographic lattice of 351 cities and towns (hereafter referred to as towns). We aggregated FCP data by town and by broad ownership class (public [municipal, state, federal] or private [non-industrial private, trusts, corporate, industrial]). Forest ownership statewide is distributed into these categories: federal (1.9%), state (19.1%), county and municipal (12%), private corporate (10.5%), and non-industrial private (56.4%; Oswalt et al. 2014). These ownership classes are not evenly distributed between all towns. For purposes of a statewide analysis, coarser public/private aggregation was made, ensuring that almost all towns had some of each ownership class. This aggregation provided an estimate of the area (ha) and number of harvest events, annually, by public and private ownership for each town. In many towns, commercial harvest activity is rare, such that annual harvest analysis includes many zero values. To facilitate statistical analyses, data were binned into five-year classes for each town, providing an estimate of the area and number of events, by public and private

ownership, for each town for six individually analyzed time periods: 1984–1988, 1989–1993, 1994–1998, 1999–2003, 2004–2008, and 2009–2013. We plotted annual values and examined alternative temporal windows to ensure that the selection of these particular time periods did not affect the results (Appendix S1: Fig. S1).

We excluded 23 of the 351 Massachusetts towns that are economically and biogeographically distinct from the rest of the state and have an acute lack of forest and harvest activity. These included the island towns on Nantucket and Martha's Vineyard (both islands off the Massachusetts coast), as well as towns on Cape Cod (a densely populated and highly developed peninsular coastal tourist region), resulting in 328 towns in this analysis, representing an overall area of 19,479 km^2. The mean area of a town is 59.4 km^2 (minimum = 3.0 km^2, maximum = 265.8 km^2, and standard deviation = 33.5 km^2).

Land-use data

To estimate forest area for each town during each of the six time periods, we calculated the percent forest cover from the best available land-cover maps representing the closest time period (Table 1). Estimates of forest area for 1985 (use for the first period) and 1999 (use for the second and third) were derived from photo-interpreted aerial photography for Massachusetts (MacConnell et al. 1991, MassGIS 2015). National Land Cover Data

(NLCD) was used to derive estimates of forest area for 2001, 2006, and 2011 (Homer et al. 2015), which were used for the fourth, fifth, and sixth period, respectively. NLCD estimates were derived using a different rubric and thus are not directly comparable to earlier estimates of photo-interpreted land cover. Both methods nonetheless provide a reliable estimate of the forest cover in each town during each of the six time periods. These estimates were compared to the total land area in each town to derive an estimate of the percent forest by town for each of the six time periods we analyzed.

To estimate the amount of public and private forest land in each town, we compared the amount of forest land within private and public ownership to the total forest area. For each time period, we combined these estimates of public and private forest area with town harvest data to generate estimates of the proportion of public and private forest harvested in each town for each time period. Estimates of ownership were acquired from the Protected and Recreational Open Space maintained by MASSGIS.

Demographic data

We assembled a wide variety of socioeconomic and demographic data hypothesized to impact harvesting (see review in *Introduction*), by town, for a variety of points in time. These included number of residential building permits/ha (2000, 2006, 2012); median household income (1979,

Table 1. Independent variables used within regression models for 328 towns in Massachusetts.

Parameters	Variable	Mean	Standard error	Source
Percent forest	1985	55.4	1.23	MassGIS
	1999	52.5	1.24	MassGIS
	2001	56.5	1.35	NLCD
	2006	56.5	1.36	NLCD
	2011	56.4	1.36	NLCD
Median household income ($)	1979	20,509	564	U.S. Census†
	1989	42,411	648	U.S. Census†
	1999	59,285	1,035	U.S. Census†
	2006–2010	76,908	1,298	U.S. Census†
Distance from Boston (km)		74.5	2.9	Considering each town as a polygon, the linear distance from each town's polygon centroid to Boston (km)

Notes: NLCD, National Land Cover Data. Household income from the 1980 to 2000 decennial Census refers to income the previous year (1979, 1989, and 1999). Household income from the American Community Survey refers to income earned during the 12 months prior to completing the questionnaire. Incomes were adjusted for inflation using the annual average consumer price index for all urban consumers compiled by the U.S. Department of Labor, Bureau of Labor Statistics: 1979 = 72.6; 1989 = 124.0; 1999 = 166.6; and 2010 = 218.1, where the 1982–1984 average = 100.

† 1980 Census Summary Tape File 3 (STF3); 1990 Census Summary File 3 (SF3); 2000 Census Summary File 3 (SF3); 2010 American Community Survey (ACS) five-year Summary File.

1989, 1999, 2006–2010); median home price (2000, 2005, 2013); population density (1980, 1990, 2000, 2010); road density (2013; km/km^2); and distance to Boston (km). We compared them all through Pearson's correlation to avoid using those that were highly intercorrelated (i.e., $|r| > 0.7$; sensu Dormann et al. 2013) in the same statistical model. Many of these variables exceeded this threshold. The two variables that contained the most independent information and were broadly reflective of the larger suite of variables were median household income (1979, 1989, 1999, 2006–2010) and distance to Boston; therefore, we included these as independent variables within the regression model comparison and analyses. See Table 1 for a description of data and sources.

Rural, suburban, and urban classification

Since population density, percent forest, and other characteristics vary significantly between metropolitan Boston and the rural portions of the state, we classified all towns into rural, suburban, or urban categories. We used a unique heuristic developed by Short Gianotti et al. (2016) that is based on landowner perceptions of their towns. Short Gianotti et al. used a mail survey of landowners in towns along two 100-km transects that emanate from Boston and extend westward across the urban–rural interface. Landowners were asked to self-identify as living in an urban, suburban, or rural location. Subsequent analysis of respondent impressions and customary variables used to describe urbanization (e.g., population density, impervious surface area) identified a model that predicted perceived urban–suburban status well (with an accuracy of approximately 84%). According to respondent perceptions of their town, those with population density <94 people/km^2 were classified as rural, between 94 and 1312 people/km^2 were classified as suburban, and >1312 people/km^2 were urban. We applied these definitions based on population density data from 1980, 1990, 2000, and 2010 to generate estimates of urban, suburban, and rural communities through time. In addition to analyzing the occurrence of harvest according to a variety of continuous variables (Table 1) that describe towns, we also investigated the occurrence of harvesting in towns according to this classification to better understand harvest differences between suburban and rural conditions.

Data analysis

To assess temporal trends in the proportion of study towns supporting one or more harvests within a time period throughout the past 30 yr, we fit a linear model where the dependent variable was the percent of towns with one or more harvest events in a time period and the independent variable was the series of five-year time periods. We did this separately for public and private harvests. Similarly, to understand whether there was a temporal trend in the average extent of towns' forest subject to harvest, we fit a linear model to the time series of average harvest extents (i.e., the mean percent of private or public lands harvested across all study towns). Next, to understand whether there was a significant temporal trend in harvest activity in each of the individual towns, we fit linear models of the harvest extent across the times series within each town. We then mapped the location of towns with and without a significant increasing or decreasing trend ($P < 0.1$).

For each of the six time periods, we then evaluated a series of regression models characterizing the relationships between harvest activity and the independent variables described in the demographic and land-use data described above, based on parsimony and explanatory power. We fit and compared models that estimated the probability that harvesting occurred in a town during the time period (i.e., what probability would generate the observed number of towns with harvests, given the number of trials or towns). Next, using only those towns where harvesting occurred during the time period, we fit and compared models that estimated the proportion of forest land in a town that supported harvesting within each time period. We conducted these analyses separately for private and public forests. We used a model comparison protocol that tested a hierarchy of models of increasing complexity using an information theoretic approach and the Akaike information criterion (AIC; sensu Burnham and Anderson 2002). For each time period, we first fit a null model that included only the mean of the response, and compared this to a suite of models that included one, two, and three predictor variables. We report the AIC statistic and the Akaike weights (w_i), which are the weight of evidence in favor of model i being the actual best model, given the suite of models examined.

We used an exponential model to describe the probability of a town including harvests as a function of the percent forest in the town (sensu Canham et al. 2013):

$$\text{Prob(logging}_i) = 1 - [ae^{-mX_i^b}] \quad (1)$$

where X_i is percent forest in the ith town and a, m, and b were estimated parameters. The parameters specify the effective probability of harvest as a function of percent of a town that is forested. Alternate models specified the X_i, a, m, and b parameters as functions of combinations of the predictor variables. The likelihood function for the frequency models was:

$$\text{Log likelihood}$$
$$= \sum_i \begin{cases} \log(\text{Prob(logging}_i)) & \text{if town } i \text{ was logged} \\ \log(1 - \text{Prob(logging}_i)) & \text{if town } i \text{ was not logged} \end{cases}$$
$$(2)$$

We assessed the goodness of fit of the frequency models based on the coefficient of determination, $D = \hat{\bar{\pi}}_1 - \hat{\bar{\pi}}_0$, denoting the average of the fitted probability estimates for successes (towns with harvest) minus the average of the fitted probability estimates for the failures (towns without harvest; Tjur 2009).

When fitting and comparing models of the harvest proportion, we used the negative exponential form to compare against:

$$\text{FH}_i = a\exp(-mX_i^b)$$

where FH = forest harvested as the proportion of that class of forest (private or public) subject to harvest in the period, X_i is the predictor variable (e.g., proportion of forest in a town) in the ith town, and a, m, and b were estimated parameters. Again, we compared a null "means model" to alternate models that specified the X_i, a, m, and b parameters as functions of combinations of the predictor variables. For each model, we report the AIC, the w_i, and the R^2. The likelihood function for the proportion models was gamma-distributed. We solved for the maximum-likelihood values of the parameters in both sets of models using 20,000 iterations of simulated annealing in the Likelihood library (Murphy 2015) for the R statistical software package (R Development Core Team 2016).

RESULTS

Harvest patterns over time

In any given five-year period, between 64.0% and 73.5% of towns experienced one or more harvests on private forestland with no significant trend over time ($P = 0.61$). The occurrence of harvest was lower on public forest (ranging from 30.8% to 42.2%) with no significant temporal trend ($P = 0.21$; Fig. 2). For those towns that had harvest within a time period, the average percent of towns'
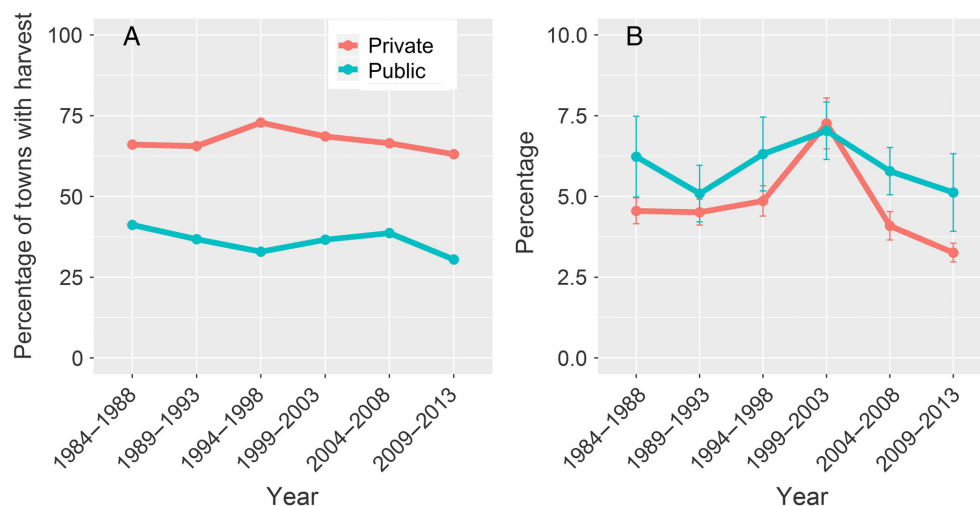

Fig. 2. (A) Percent of eligible towns that experienced a harvest during each time period. (B) For only those towns that had >1 harvest in a time period, the average percent of towns' public or private forest area that supported harvest throughout that time period. Error bars = 95% CI for the mean.

forest area that supported harvest ranged from 3.3% to 7.3% for private lands and 5.1% to 7.0% for public lands, and neither the private extent nor the public extent of harvesting had a significant temporal trend ($P = 0.66$, $P = 0.71$, respectively; Fig. 2).

The analysis of changes in the harvest extent on private land within the individual towns showed that, of the 328 study towns, 325 (93%) had no temporal trend. Of the 23 with a significant trend ($P < 0.1$), six (2%) increased over time

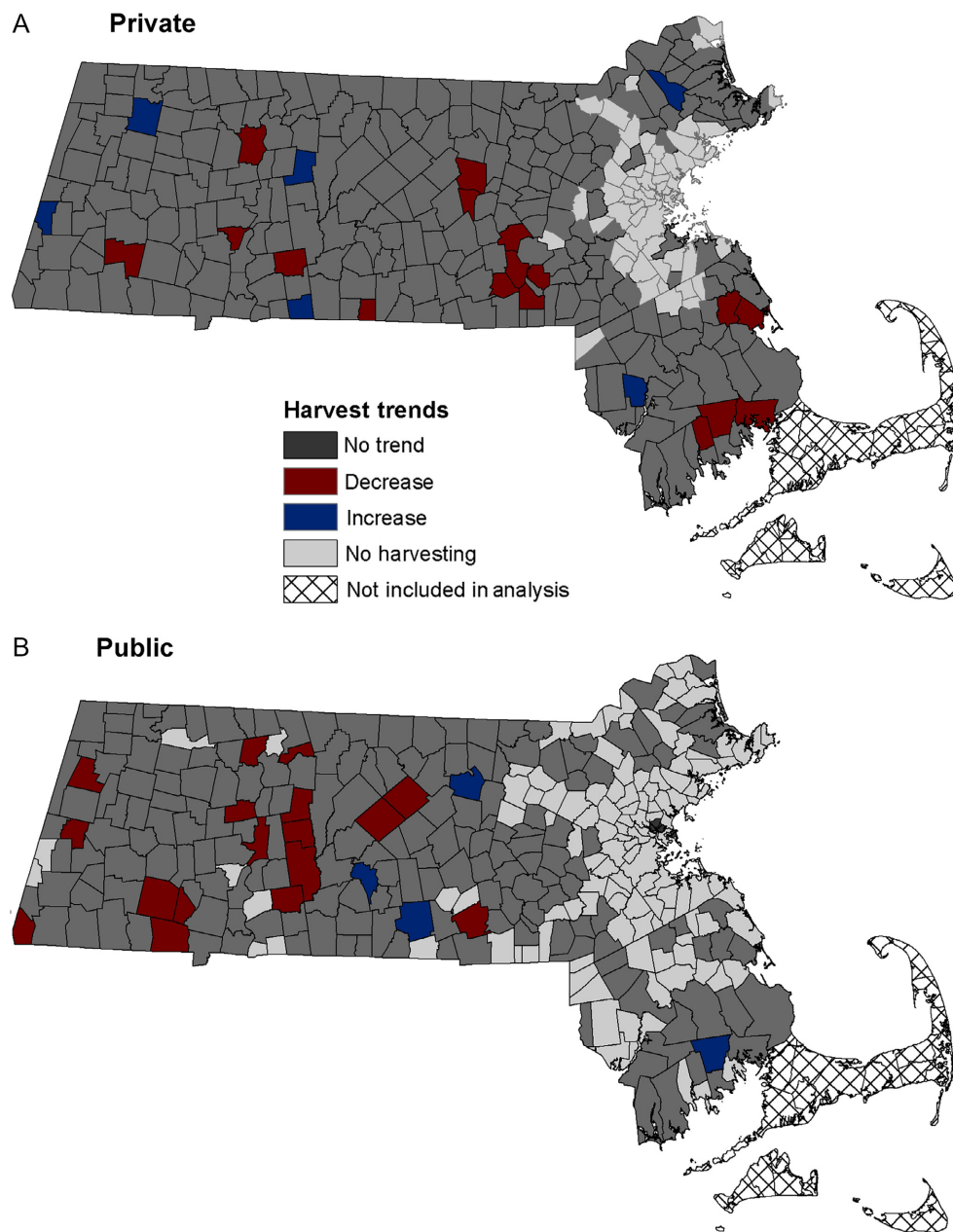Fig. 3. Temporal trends in timber harvesting within Massachusetts towns during the past 30 yr on private (A) and public (B) lands. Towns in red experienced a statistically significant ($P < 0.1$) negative trend in harvest activity across the six consecutive five-year time windows. Towns in blue had an increase in harvest activity. Light gray towns had no harvest activity in any of the five-year time periods.

Table 2. The probability of harvest on private land.

Predictor variables	AIC_i	w_i	D
1984–1988 ($n = 328$)			
Response mean (null)	421.84	0	0
%Forest	246.01	0	0.47
DistBoston	318.84	0	0.19
HHMI	407.49	0	0.04
%Forest + DistBoston	**193.76**	**0.78**	**0.58**
%Forest + HHMI	239.31	0	0.49
DistBoston + HHMI	359.59	0	0.19
%Forest + DistBoston + HHMI	196.26	0.22	0.58
1989–1993 ($n = 328$)			
Response mean (null)	424.46	0	0
%Forest	273.72	0	0.41
DistBoston	336.4	0	0.17
HHMI	412.89	0	0.03
%Forest + DistBoston	**252.01**	**0.88**	**0.44**
%Forest + HHMI	267.32	0	0.43
DistBoston + HHMI	333.1	0	0.18
%Forest + DistBoston + HHMI	256.08	0.12	0.44
1994–1998 ($n = 328$)			
Response mean (null)	385.5	0	0
%Forest	235.75	0	0.45
DistBoston	278	0	0.2
HHMI	382.74	0	0.02
%Forest + DistBoston	**199.53**	**0.49**	**0.5**
%Forest + HHMI	230.16	0	0.45
DistBoston + HHMI	380.1	0	0.2
%Forest + DistBoston + HHMI	**199.44**	**0.51**	**0.52**
1999–2003 ($n = 328$)			
Response mean (null)	410.22	0	0
%Forest	223.24	0	0.51
DistBoston	319.49	0	0.18
HHMI	408.45	0	0.01
%Forest + DistBoston	**198.8**	**0.85**	**0.56**
%Forest + HHMI	218.64	0	0.52
DistBoston + HHMI	350.74	0	0.18
%Forest + DistBoston + HHMI	202.33	0.15	0.56
2004–2008 ($n = 328$)			
Response mean (null)	420.48	0	0
%Forest	250.8	0	0.46
DistBoston	319.9	0	0.19
HHMI	409.3	0	0.04
%Forest + DistBoston	**197**	**1**	**0.56**
%Forest + HHMI	226.78	0	0.51
DistBoston + HHMI	387.77	0	0.2
%Forest + DistBoston + HHMI	254.55	0	0.4
2009–2013 ($n = 328$)			
Response mean (null)	433.9	0	0
%Forest	248.51	0	0.49
DistBoston	345.35	0	0.17
HHMI	423.97	0	0.03
%Forest + DistBoston	**211.09**	**0.87**	**0.5**

and 17 (5%) decreased (Fig. 3A). There was no apparent spatial pattern in the distribution of these towns (Fig. 3A). Of the 325 study towns with public forest, 304 (94%) had no temporal trend, while four (1%) had a significant increasing trend and 17 (5%) had a significant decreasing trend. Again, there was no apparent spatial pattern (Fig. 3B).

Private harvest

Probability of harvest.—In all six time periods, the best model estimating the probability of harvest on private forest in a given five-year period included distance to Boston and the percent forest cover in the town (Table 2). In one time period (1994–1998), there was equal support for a full model, which also contained household median income. The probability of harvest on private land in a given five-year period is greater as percent forest and distance increase (Fig. 4). There was no discernable difference between the fit of the best models among the six time periods. To maximize the clarity of the presentation, we have not plotted the two-unit support intervals around the model fits (but see Appendix S1: Table S1 for support intervals).

Proportion of private forest harvested.—We excluded towns in which no private harvest occurred in a given five-year period, and estimated models to predict the proportion of a town's private forest that would host a harvest (by area). In four of six time periods, the best model estimating the proportion of a town's private forest area that would be harvested is based on percent forest and median household income (Table 3). In 1994–1998 and in 2004–2008, the best model also included the distance to Boston. Percent forest remains positively related to the proportion of a town's private forest that is

(Table 2. *Continued*)

Notes: Comparison of logistic regression models estimating the probability of harvest on *private land* during the specified time period. Bold text indicates the best model of those evaluated per the Akaike weights (w_i). D denotes the coefficient of determination, a statistic of model fit (see *Materials and Methods*). %Forest: percent of town with forest land cover; DistBoston: the Euclidian distance from the City of Boston to the centroid of the town; HHMI: the area-weighted mean of census track household median income within the town; AIC, Akaike information criterion.
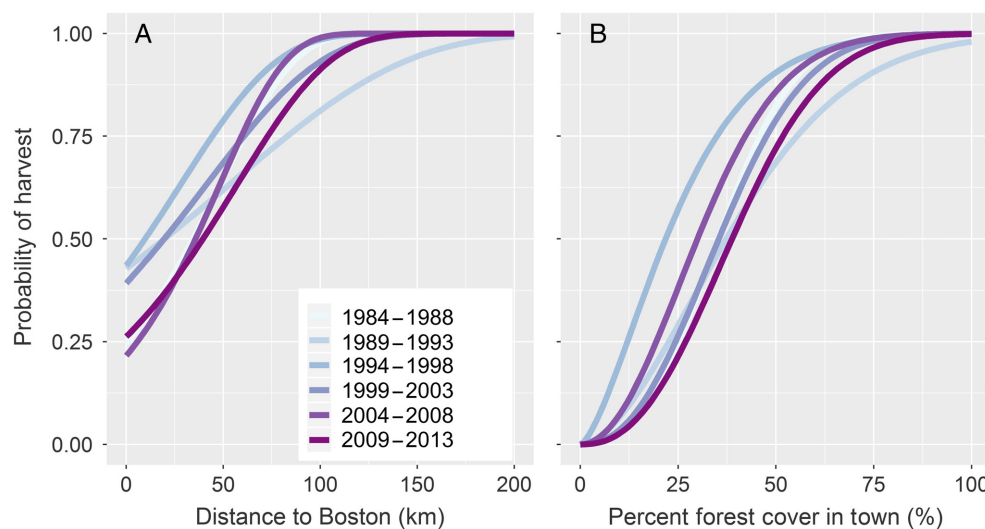
Fig. 4. Logistic models of the probability of harvest on private forest within six consecutive five-year periods, based on both distance to Boston and percent forest in a town. Plot (A) shows the effect of distance to Boston while forest cover is held constant at 55% (statewide mean value). Plot (B) shows the effect of percent forest cover while the distance to Boston is held constant at the statewide mean value of 74 km.

harvested, and the town's median household income is negatively related (Fig. 5).

Public harvest

Probability of public harvest.—The models estimating the probability of harvest on public forest in a town have less explanatory power than those developed for private land, as evidenced by the lower D statistic (Table 4). The probability of private harvest is most strongly and consistently estimated by a combination of percent forest and distance to Boston. The probability of public harvest does not have consistent predictor variables between periods (Table 4), implying more variation and a lack of consistent influences. Percent forest is always a relevant independent variable, but either alone (two periods) or in combination with distance to Boston (four periods).

Interestingly, in no five-year period does the probability ever reach 1.0, and in some, it only reaches as high as 0.6, even for heavily forested towns (Fig. 6). Percent forest is strongly, consistently, and positively related to the probability of public harvest (Fig. 6), but nonetheless the probability never reaches 1.0 even in the most heavily forested towns.

Proportion of public forest harvested.—Models estimating the proportion of a town's public forest that hosts a harvest in a five-year period have no explanatory power ($R^2 < 0.01$; Appendix S1: Table S1). Since we were estimating the proportion of forest that was harvested, we excluded towns from the analysis that had no public harvest in a given five-year period. In each time period, the null model containing only the statewide average had the highest weight. In other words, we found no biophysical or social variables that show a relationship to the proportion of a town's public forest that hosts a harvest. This acute lack of a relationship implies that eastern towns with relatively little forest that have a harvest are just as likely to have the same proportion of public harvest as western towns with abundant forest that have a harvest. While percent forest and distance to Boston variously combine to influence the probability of whether or not a harvest will occur on public land (Table 4), the relative proportion of a town's public forest that hosts a harvest appears to defy estimation based on the social and biophysical variables we used, and that were relevant in other models estimating harvest.

Table 3. The extent of harvest on private land.

Predictor variables	AIC_i	w_i	R^2
1984–1988 ($n = 217$)			
Null model	1091.48	0	0
%Forest	1013.36	0	0.265
DistBoston	1033.83	0	0.113
HHMI	1042.27	0	0.149
%Forest + DistBoston	1000.17	0	0.25
%Forest + HHMI	**973.2**	**0.84**	**0.339**
DistBoston + HHMI	1021.07	0	0.167
%Forest + DistBoston + HHMI	976.5	0.16	0.334
1989–1993 ($n = 215$)			
Null model	1078.51	0	0
%Forest	1006.76	0	0.212
DistBoston	1029.95	0	0.098
HHMI	1046.41	0	0.115
%Forest + DistBoston	1000.26	0.06	0.206
%Forest + HHMI	**995.51**	**0.66**	**0.25**
DistBoston + HHMI	1028.89	0	0.13
%Forest + DistBoston + HHMI	997.28	0.27	0.24
1994–1998 ($n = 239$)			
Null model	1237.84	0	0
%Forest	1146.46	0	0.304
DistBoston	1137.86	0	0.221
HHMI	1198.58	0	0.135
%Forest + DistBoston	1114.19	0.39	0.317
%Forest + HHMI	1128.96	0	0.343
DistBoston + HHMI	1138.52	0	0.231
%Forest + DistBoston + HHMI	**1113.26**	**0.61**	**0.334**
1999–2003 ($n = 225$)			
Null model	1344.402	0	0
%Forest	1260.85	0	0.209
DistBoston	1261.96	0	0.116
HHMI	1284.41	0	0.154
%Forest + DistBoston	1229.82	0	0.209
%Forest + HHMI	**1203.98**	**0.77**	**0.274**
DistBoston + HHMI	1252.86	0	0.158
%Forest + DistBoston + HHMI	1206.35	0.23	0.243
2004–2008 ($n = 218$)			
Null model	1052.84	0	0
%Forest	946.16	0	0.398
DistBoston	974.03	0	0.182
HHMI	1027.08	0	0.073
%Forest + DistBoston	923.43	0.02	0.379
%Forest + HHMI	919.09	0.19	0.414
DistBoston + HHMI	976.22	0	0.184
%Forest + DistBoston + HHMI	**916.3**	**0.78**	**0.401**
2009–2013 ($n = 207$)			
Null model	905.81	0	0
%Forest	853.52	0	0.256
DistBoston	863.23	0	0.099
HHMI	866.67	0	0.093
%Forest + DistBoston	844.28	0	0.229
%Forest + HHMI	**817.97**	**0.68**	**0.285**

(Table 3. *Continued*)

Predictor variables	AIC_i	w_i	R^2
DistBoston + HHMI	855.65	0	0.121
%Forest + DistBoston + HHMI	819.51	0.32	0.294

Notes: Comparison of regression models estimating the proportion of a town's private land subject to harvest within the specified time period. Bold text indicates the best model of those evaluated per the Akaike weights (w_i). %Forest: percent of town with forest land cover; DistBoston: the Euclidian distance from the City of Boston to the centroid of the ith town; HHMI: the area-weighted mean of census track household median income in the town; AIC, Akaike information criterion.

Harvest by rural and suburban conditions

Based on the land owner-defined classification of rural, suburban, and urban that we used (i.e., after Short Gianotti et al. 2016, a function of population density), there was a shift in the distribution of rural and suburban towns. Population density data from 1980 indicate 128 rural, 172 suburban, and 28 urban towns. By 2010, the number of rural towns had declined to 104 and the number of suburban towns had climbed to 196 (Fig. 7). Between 1980 and 2010, there were two towns that changed from suburban to rural due to slight declines in population density (e.g., 116.2–89.5/km^2), but the majority of the shift was from the rural to suburban condition (i.e., 26 towns). During this period, there was no change in the number of urban towns (i.e., 28).

We compared the proportion of a town's public or private forest harvested in the five-year periods based on rural and suburban status (Fig. 8). We omitted consideration of harvest activity in urban towns since there were very few observations of harvest during the five-year periods (e.g., 0, 1, or 2). The proportion of private forest that was harvested in rural towns was consistently significantly greater than that of private forest harvested in suburban towns (Fig. 8). In contrast, there was no difference in the proportion of public forest harvested in rural and suburban towns. Though we observed an increase in the number of suburban towns between 1980 and 2010, private and public harvest still occurred according to our metric of proportion of a town's forest area harvested in a five-year period. We did not analyze volume harvested or intensity of harvest (i.e., m^3/ha) to identify an overall statewide effect of this shift from rural to suburban, since we were studying this phenomenon at the town rather than statewide level.
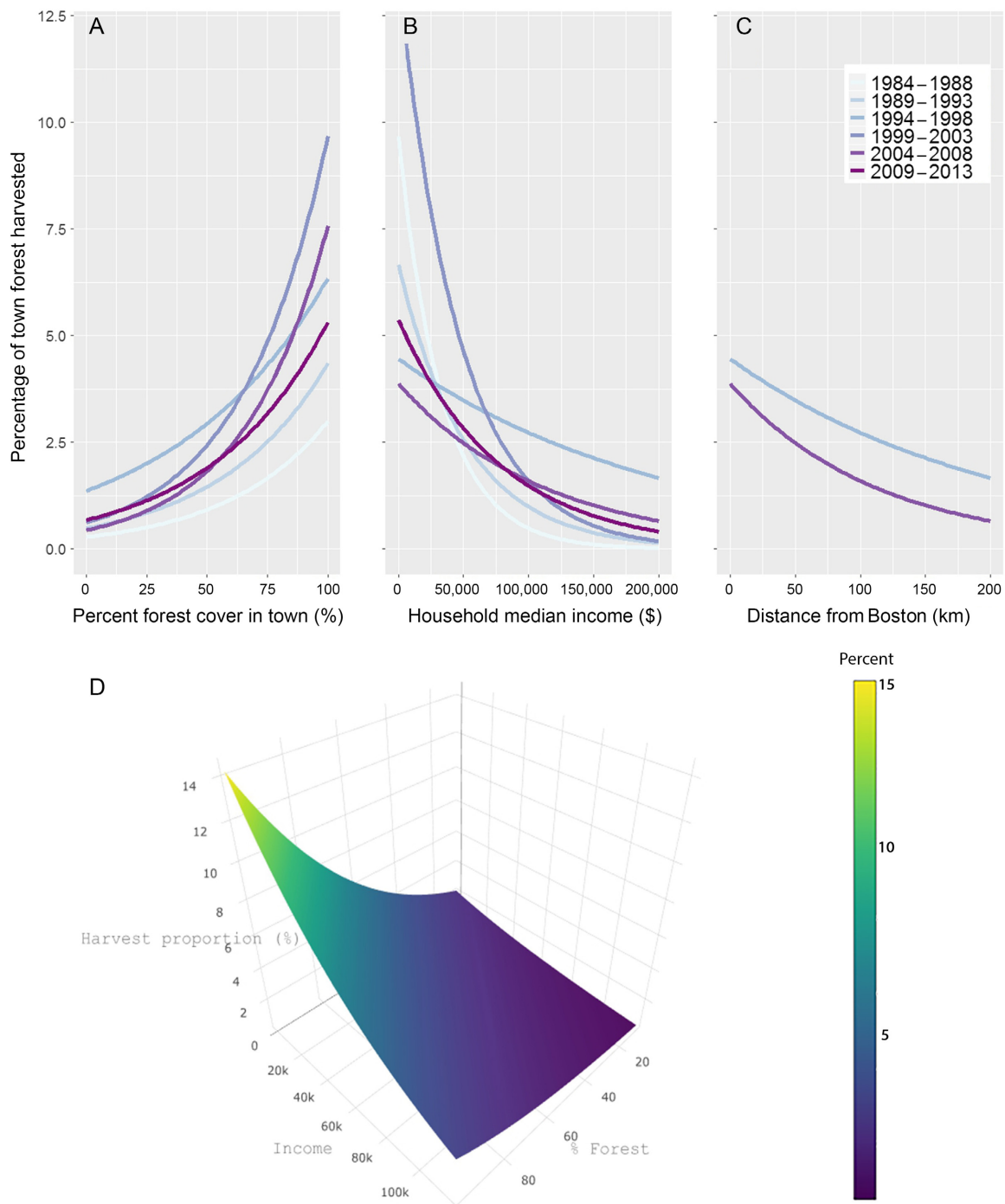
Fig. 5. Predicted proportion of a town's private forest harvested in six consecutive five-year periods. Lines show the best model for each time period. Note that the best model for two time periods (1994–1998 and 2004–2008) also includes distance to Boston. Plot (A) shows the effect of percent forest cover while household median income (HHMI) is held constant at the statewide mean value of $77,000. Plot (B) shows the effect of HHMI while forest cover is held constant at 55% (statewide mean value). Plot (C) shows the effect of distance to Boston while percent forest and HHMI are held constant at the statewide average. Plot (D) shows the 3D model surface for the 2009–2013 time period.

Table 4. The probability of harvest on public land.

Predictor variables	AIC$_i$	w_i	D
1984–1988 (n = 325)			
Null model	443.21	0	0
%Forest	350.67	0	0.27
DistBoston	374.18	0	0.18
HHMI	423.71	0	0.05
%Forest + DistBoston	**334.35**	**0.81**	**0.31**
%Forest + HHMI	343.81	0.01	0.28
DistBoston + HHMI	375.18	0	0.18
%Forest + DistBoston + HHMI	337.3	0.18	0.32
1989–1993 (n = 325)			
Null model	431.12	0	0
%Forest	341.16	0.13	0.25
DistBoston	377.37	0	0.15
HHMI	421.12	0	0.04
%Forest + DistBoston	**337.86**	**0.7**	**0.27**
%Forest + HHMI	342.31	0.08	0.26
DistBoston + HHMI	380.01	0	0.15
%Forest + DistBoston + HHMI	342.02	0.09	0.26
1994–1998 (n = 325)			
Null model	415.28	0	0
%Forest	**350.98**	**0.52**	**0.17**
DistBoston	391.46	0	0.07
HHMI	408.2	0	0.03
%Forest + DistBoston	352.93	0.2	0.17
%Forest + HHMI	352.52	0.24	0.17
DistBoston + HHMI	395.11	0	0.08
%Forest + DistBoston + HHMI	356.16	0.04	0.18
1999–2003 (n = 325)			
Null model	430.06	0	0
%Forest	368.04	0	0.18
DistBoston	390.78	0	0.11
HHMI	416.61	0	0.05
%Forest + DistBoston	**352.86**	**0.97**	**0.24**
%Forest + HHMI	359.9	0.03	0.21
DistBoston + HHMI	390.98	0	0.12
%Forest + DistBoston + HHMI	363.21	0.01	0.21
2004–2008 (n = 325)			
Null model	436.92	0	0
%Forest	346.04	0.01	0.25
DistBoston	373.59	0	0.16
HHMI	420	0	0.05
%Forest + DistBoston	**336.21**	**0.98**	**0.28**
%Forest + HHMI	345.35	0.01	0.26
DistBoston + HHMI	375.3	0	0.18
%Forest + DistBoston + HHMI	366.49	0	0.22
2009–2013 (n = 325)			
Null model	403.22	0	0
%Forest	**346.78**	**0.3**	**0.17**
DistBoston	391.64	0	0.07
HHMI	401.69	0	0.05
%Forest + DistBoston	347.13	0.25	0.16
%Forest + HHMI	347.66	0.19	0.16

(Table 4. *Continued*)

Predictor variables	AIC$_i$	w_i	D
DistBoston + HHMI	392.55	0	0.07
%Forest + DistBoston + HHMI	347.13	0.25	0.17

Notes: Comparison of logistic regression models estimating the probability of harvest on *public land* during the specified time period. Bold text indicates the best model of those evaluated per the Akaike weights (w_i). D denotes the coefficient of determination, a statistic of model fit (see *Materials and Methods*). %Forest: percent of town with forest land cover; DistBoston: the Euclidian distance from the City of Boston to the centroid of the town; HHMI: the area-weighted mean of census track household median income within the town; AIC, Akaike information criterion.

DISCUSSION

Lack of a temporal trend

Thirty years of data for 328 contiguous towns that span urban-to-rural circumstances affords an excellent opportunity to observe the change in probability of harvest over time. The data do not provide a convincing signal of a temporal effect (Figs. 2A, B, 3A, B). This is surprising, given that overall population densities increased between 1980 and 2010, and thus shifted 26 towns from rural to suburban in the eastern and central portions of the state (Fig. 7), and there are significant differences between the proportion of a town's private forest that is harvested in rural and suburban communities (Fig. 8). Should population density continue to increase, and more towns shift from rural to suburban, our results suggest that a downward trend in the proportion of a town's private forest that is harvested would be likely to follow. However, for the study period, our results do not indicate a clear effect of time on harvest probability over the past 30 yr. It is possible that the suburban-to-rural interface in Massachusetts is relatively stable in the period we observed, and more dramatic changes could have been evident earlier, under more dynamic shifts in communities from rural to suburban. Also, it is worth noting that our metric of harvest activity (proportion of a town's public or private forest that hosts a harvest in a five-year period) is rather conservative, and it would only take one harvest in five years in a town to indicate harvest activity; also, it does not speak to any potential changes in timber harvest intensity.
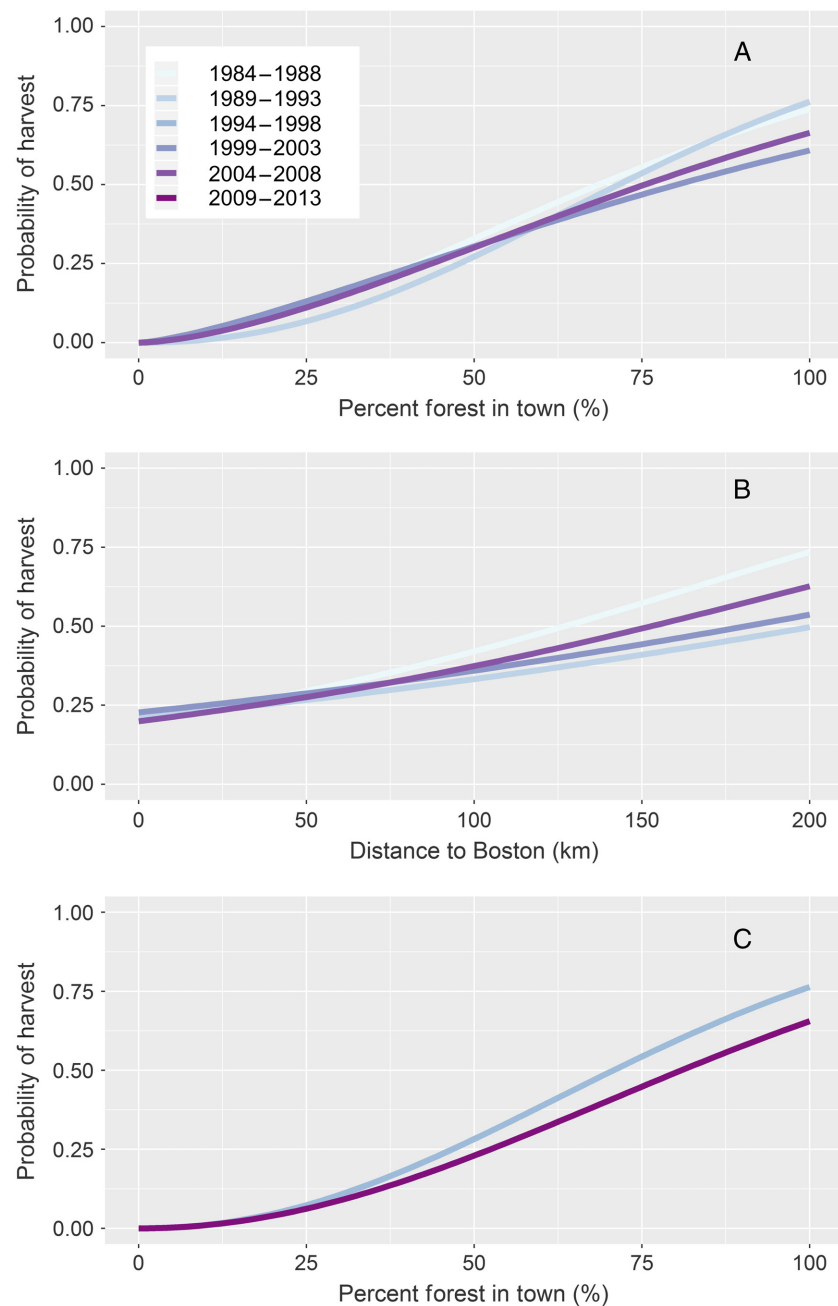
Fig. 6. Predicted probability of harvest on public lands. (A) For the four models that use both percent forest and distance to Boston, distance to Boston is held constant at the mean of 74 km. (B) For the four models that use both percent forest and distance to Boston, percent forest is held constant at 55%. (C) Two models that rely only on percent forest.

Overall occurrence or probability of harvest

In spite of being densely populated and dominated by small, private non-corporate ownerships typically thought of as being disinterested in harvest (e.g., Butler 2008), private land in Massachusetts is being harvested and this management practice and ecological disturbance have been occurring consistently across the
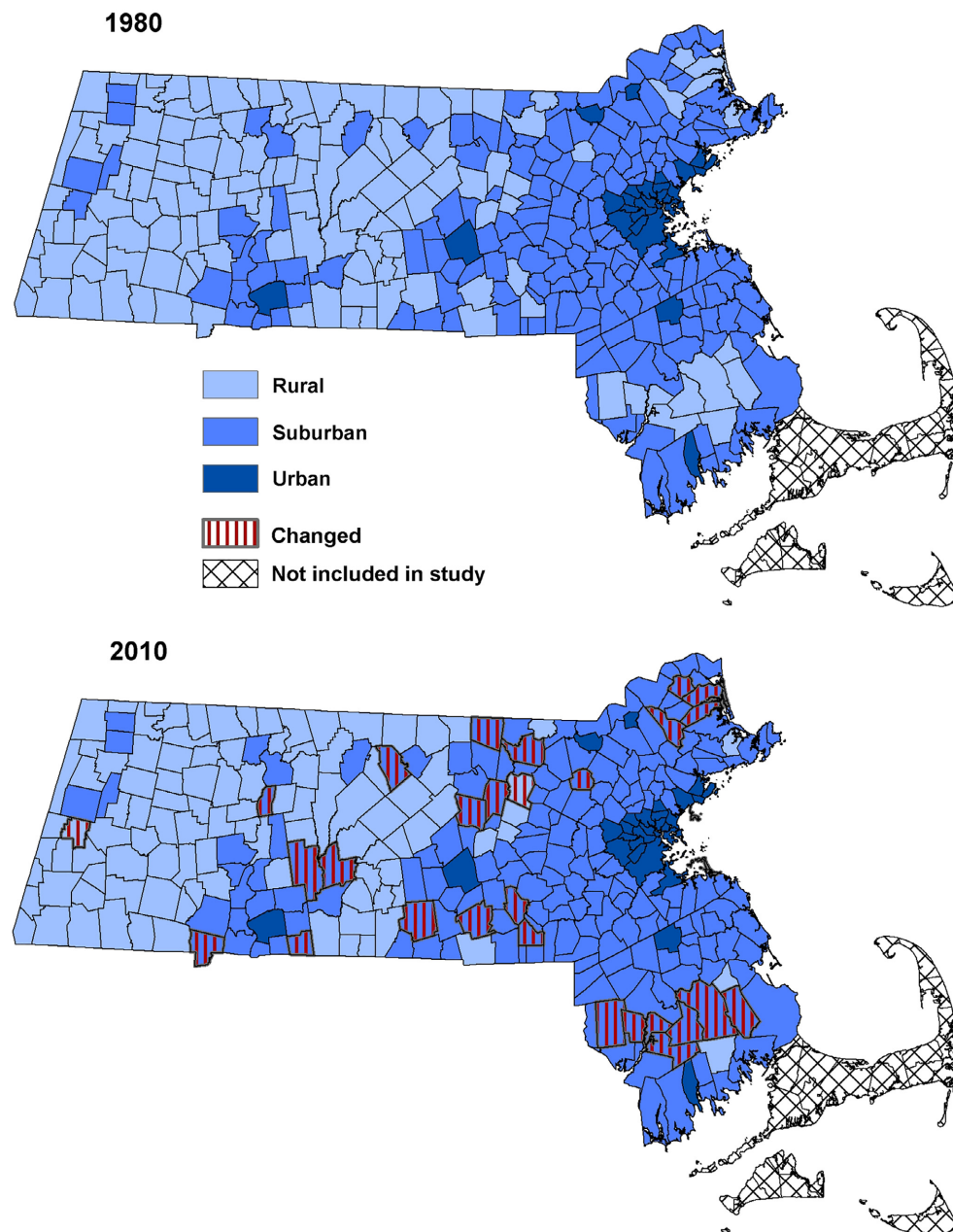
1980

2010

Fig. 7. Distribution of rural, suburban, and urban towns, 1980 and 2010, based on population density after the analysis of Short Gianotti et al. 2016 (i.e., rural < 94/km^2; suburban 94–1321/km^2; urban >1321/km^2).

suburban–rural continuum over a 30-yr period. The probability that private harvest will occur in a town is predictable based on combined effects of distance to Boston and the percent of forest land use in a town. Public harvest probability is similarly best estimated by the combination of distance to Boston and the percent of forest in a town. In two time periods, percent forest alone represents the best model. While this land use is logically related to the distance to Boston across the rural–urban interface, it essentially met the test of being included in the models with distance to Boston, due to correlations below 0.7 (r = 0.66, 0.70, 0.65, 0.67, and 0.67, respectively).
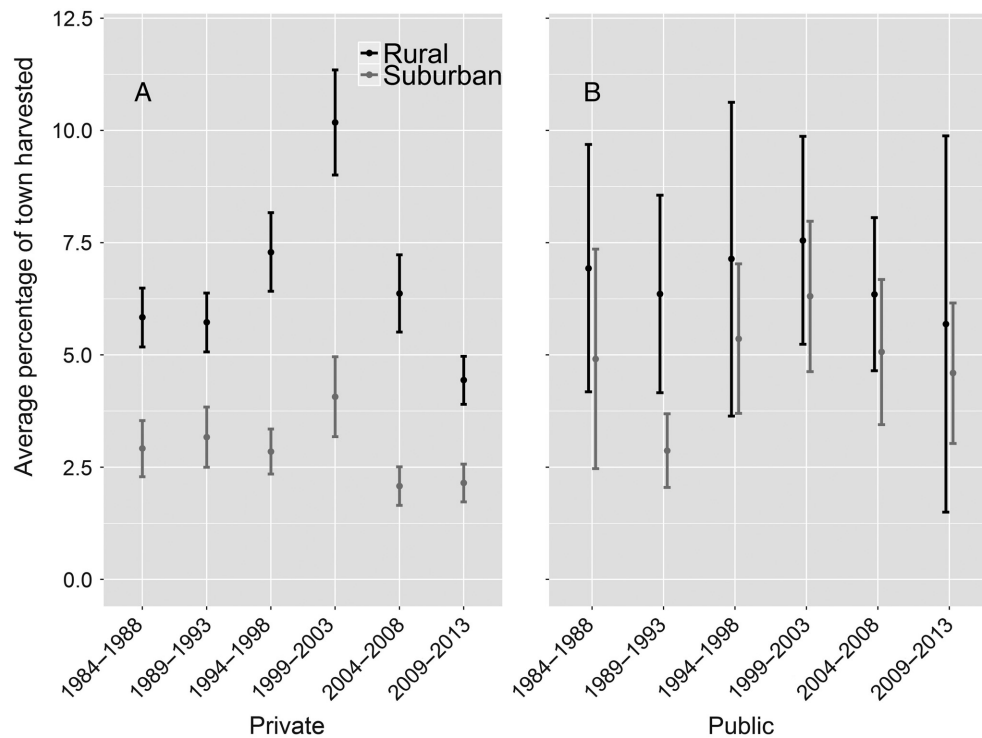
Fig. 8. Proportion of a town's public (A) or private (B) forest harvested in a five-year period, by rural or suburban classification (after Short Gianotti et al. 2016), with 95% confidence intervals.

In all probability-of-harvest models estimated, percent forest was a significant and positively related variable. More heavily forested towns have a higher probability of harvest of both private and public land. Interestingly, however, even under very high percentages of forest land use, model estimates of public harvest probability do not exceed 0.75 (Fig. 6). A heavily forested town is not necessarily guaranteed a public harvest. Similarly, towns with <40% forest have less than a 20% probability of public harvest (Fig. 6). Percent forest has a differential effect on the probability of harvesting on public or private forest. Said in another way, the ownership status of a forest (i.e., whether public or private) has an influence on its likelihood of harvest. The inconsistent relationship between increasing forest in a town and probability of harvest is surprising and raises questions about the public dialogue and process surrounding public harvests in Massachusetts. The decision to harvest on private forest is relatively simple, involving one or several owners, or perhaps spanning one or two generations. Reasons can vary, ranging from need for income, to enhancing wildlife habitat, or treating a stand to improve future growth. The same reasons can apply to public land, but the decision-making process can be quite different, involving agency procedures and mandate, local stakeholder opinion, and diverse ownership objectives. The difference in maximum probabilities between private and public land, influenced by percent forest and distance to Boston (Figs. 4, 6), likely reflects the different relative complexities of decision making and the vagaries of agency mandate, public responsiveness, and diverse stakeholder opinion. In this analysis, "public" is admittedly a broad ownership category including municipal, state, and federal agencies, and it cannot be expected that they all make decisions in similar ways. Public lands, however, are not subject to the same intensity of parcelization and division that can affect private properties, though it is possible for towns to convert municipally held forest to some other use (e.g., school, playing fields). So larger public ownerships may be more conducive to harvest than smaller, private ones. In spite of this, at a distance of 50 km

from Boston, probability of harvest on private land in a town within a five-year time period is between 60% and 80% (Fig. 4), but at the same distance for public lands, the probability is as low as 25–30% (Fig. 6). Public land harvest never achieves a maximum of 100% regardless of location, and appears more negatively impacted at lesser distances to Boston.

Proportion of a town's forest that is harvested

The proportion of a town that is forested is similarly important for predicting the extent of private forest harvested in a five-year period, and this has been consistent over the past 30 yr (Table 3). In four of six time periods, this variable combined with a town's median household income provides the best model of the proportion of private forest harvested. In two periods, percent forest and median household income were further combined with distance to Boston to result in the best model. Interestingly, an expression of a town's relative affluence is influential in estimating the proportion of private forest harvested. Median household income has a negative influence on the relative proportion of private forest that sustains a harvest in most time periods modeled (Fig. 5). While affluence is not a factor in estimating overall probability, it is meaningful in estimating the proportion of a town's private forest that would be harvested.

The proportion of a town's public forest that was harvested cannot be predicted by the biophysical and social variables we used. It cannot be concluded that more distant rural towns, less affluent towns, or those with more or less forest cover will have a higher proportion of their public forest harvested in a given five-year period.

Categorical analysis of the proportion of private forest harvested by town and by suburban and rural areas similarly showed significant differences (Fig. 8). Since percent forest combined with relative affluence results in the best estimate of the proportion of private forest harvested in a five-year period, it is not surprising that these significant differences are found between rural, suburban, and urban towns. It is, however, interesting that though significantly different, there is nevertheless a meaningful proportion of a town's private forest that supports harvest in a five-year period in suburban areas. Private forest is harvested at roughly half the rate in suburban

towns, as in rural towns (Fig. 8). What is surprising is that though separated by 20 yr, the relative proportions of private forest harvested are not meaningfully different between suburban and rural towns (Fig. 8). This difference in the proportion of private harvest is constant, and not changing through time. Private forest in suburban towns is harvested at roughly the same rate and shows no apparent erosive effect of parcelization or other impactful influences over time. Private forest harvest appears relatively stable as a form of disturbance through the time period we studied.

Distance to Boston

The distance between a town and the region's urban center (Boston) is significantly related to the probability of private land harvest (Table 2, Fig. 4). This metric was less predictive for public land harvesting (Table 4, Fig. 6). There is obviously no magic factor related to actual physical proximity to this urban area itself, and this distance is more of an index combining many factors. Indeed, distance to Boston is highly correlated with many other socioeconomic factors such as population density$_{2010}$ (-0.76) and road density (-0.74), as well as the percent forest$_{2011}$ (0.66). We used this index as a proxy for all these variables when considering the question of harvest along a suburban-to-rural gradient. It translates easily into a spatial concept of occurrence of harvest (e.g., Fig. 4; probability of harvest on private land falls to below 50% closer than 50 km to Boston). Consequently, it aligns along a suburban-to-rural interface, whereas population or road densities are less spatially relevant. For purposes of regional planning, timber availability, or forest management relevance, it is easier to consider harvest probability in a spatial way, rather than based on varying densities or percent forest from town to town.

The distance to Boston becomes less relevant at greater distances (e.g., Fig. 4), and similar radiating effects from other cities may even become more influential (e.g., distance to New York City, Hartford, Connecticut, or Albany, New York). The interacting effects of multiple urban areas and their suburban surroundings were beyond the scope of our study. Our results show the definitive effect of this suburban-to-rural distance for private forest within 100 km of Boston.

Implications for forest ecology

Canham et al. (2013) reported that throughout the northeast "Logging is a larger cause of adult tree mortality in northeastern U.S. forests than all other causes of mortality combined," and in Massachusetts, removals from harvest exceed natural mortality by more than 20%. Unlike "natural" disturbances typical in Massachusetts (e.g., wind of varying intensities; Runkle 1982), harvest probability does not depend on aspect, slope, elevation (Kittredge et al. 2003), or proximity to the coast reflecting vulnerability to hurricanes (e.g., Boose et al. 2001). Instead, probability of harvest is influenced by a suite of biophysical and social variables such as the relative proportion of a town that is forested, and a town's proximity to Boston. The probability of harvest is also influenced by the ownership type (public or private). Proportion of a town's private forest that is harvested is also influenced by the relative affluence of the town. Thus, the largest cause of mature tree mortality is driven, in part, by the proportion of a town that is forested, and its affluence.

Suburban forests experience significantly less private harvest than rural areas, and harvest probability becomes small (i.e., <20%) when forest occupies <40% of a town's land use (Fig. 4). Mondal et al. (2013) studied private forestland in 36 states across urban–rural gradients using estimated 50-yr future projections of development, and found continued forest loss in the suburban regions, whereas rural forest was forecast to be relatively stable.

Limitations of the dataset prevent us from documenting changing in the intensity of harvests (i.e., the proportion of trees harvested within a harvest area) but other research has shown that most private woodland owners in the region remove a fraction of the total biomass (Thompson et al. 2017). If harvesting wanes in extent and intensity, forests will continue to mature in terms of biomass accumulation; indeed, growth already far exceeds removals in Massachusetts. This will result in forest communities with larger trees, and increased coarse woody debris. The forests will not be free of disturbance, as natural agents (i.e., predominantly wind-based in varying degrees, spatial extents, and intensities; e.g., Kittredge et al. 2003) will continue to occur randomly, and likely with increased frequency as a result of changing climate. This will result in increased downed dead material on the forest floor, as well as damaged live trees in the canopy. Briber et al. (2015) estimated enhanced growth of overstory trees due to canopy thinning effects associated with adjacent developed land use. This means that the overstory stems can actually grow faster, accumulate more biomass, and more rapidly approach older size or stature. Understory vegetation in these forests will continue to be impacted by high deer densities (Rawinski 2016), resulting in a new structure of mixed hardwood forest in central New England, with larger overstory trees, more down wood, and less diverse understories impacted by herbivory. These more densely populated suburban areas are also under development pressure, especially on private ownership, so it is possible that these stands will be converted to some other land use. Nevertheless, even in densely populated suburbs, forest land cover can exceed 20% (Fig. 1) and may remain undeveloped due to zoning or access limitations, protection from development through easement, or small parcel sizes that limit commercially feasible harvests. Without harvest, suburban forest will continue to mature, be subject to natural disturbance agents, and evolve into different forest communities than have been present before. Forests in landscapes with high human population densities behave increasingly like socioecological systems where social factors (e.g., density and affluence) have strong effects on ecological systems.

Implications for forest management

Kelty et al. (2008), Markowski-Lindsay et al. (2012), and INRS (2016) all estimated potentially available wood supplies for various purposes in Massachusetts, and the USDA Forest Service estimates timber supply for each state and nationally (USDA Forest Service 2012). Any estimate of potentially available wood supply, however, needs to consider the probability of harvest relative to factors such as percent forest, distance to urban center, and the relative affluence of towns. The probability and the proportion of harvest also vary depending on ownership type.

Most recent state estimates of timber available in Massachusetts report over 204 million cubic meters (172 m^3/ha; Oswalt et al. 2014), which has increased from 137.7 million m^3 (115 m^3/ha) since 1997. This is based on an estimate of timberland

defined as a minimum of 0.4 ha, and capable of growing 3.5 $m^3 \cdot ha^{-1} \cdot yr^{-1}$. However, this is likely an overestimate of availability due to a combination of suburbanization effects (e.g., smaller parcel size, reduced access due to development, fewer loggers, and markets), which reduce the probability of harvest. Programs to stimulate the timber economy (e.g., "buy local wood," "Commonwealth Quality Program") in states with high population densities, suburban circumstances, and dominance of private family forest need to be realistic in terms of outcomes and achievements. If the goal is to maintain "working forest" that will produce wood products into the future, tangible efforts to enable perpetual future access, and ownership sizes that can support commercially viable operations will be the most important. In Massachusetts, all commercial timber harvesters are licensed, and the decrease in their number in Worcester County and East (i.e., <95 km from Boston) is symptomatic of the lower probability

and the proportion of harvest on forest closer to Boston (Fig. 9). While we found no temporal trend in terms of the probability of harvest in a town in a five-year period, or in the proportion of a town's forest that is harvested in a five-year period, the steady decline in the number of licensed timber harvesters since 1983 is striking, within 95 km of Boston, as well as statewide. Harvest technology over time has improved in its efficiency, and markets for wood have evolved to include biomass for energy. It is possible that the same volume of wood can be harvested by fewer harvesters, though we did not analyze harvest volumes per operation or over time. A similar declining trend is seen in the number of sawmills in Massachusetts, from 177 in 1977 (UMass Extension 1978) to 100 in 1991 (Massachusetts Department of Environmental Management 1991) to 30 in 2006 (De la Cretaz et al. 2010). While harvest volumes, sawmill efficiencies, and the number of harvesters is an analysis beyond the scope of this
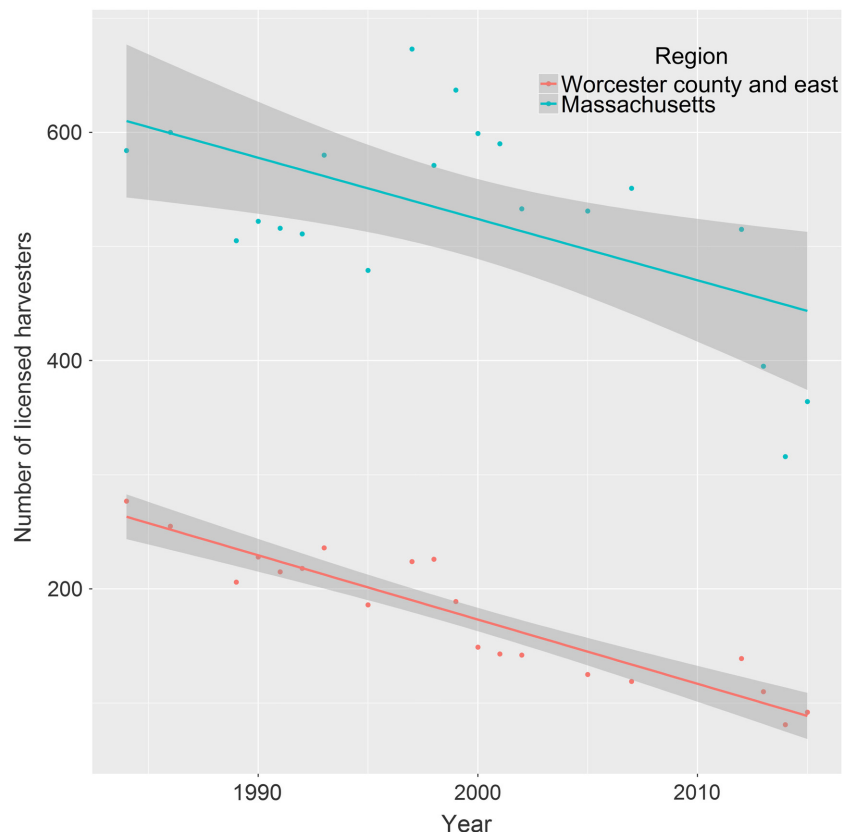

Fig. 9. Licensed timber harvesters in central and eastern Massachusetts (<95 km from Boston), and statewide total, over time, 1983 to 2015. Shaded area represents the 95% confidence interval around the linear model.

paper, the unmistakable trend is probably at least circumstantially related to shifts in towns from rural to suburban, and the related decrease in the proportion of a town's forest that is harvested. This phenomenon is illustrative of the linked socioecological system, whereby human decisions to harvest, whether private or public, influence the probability and extent of harvest. This activity is related to the rural or suburban nature of a town. As towns change, so does the role of harvest as a form of disturbance, and this has implications for the number of timber harvesters, employment, and the related local economy.

Conclusion

Unlike the predominant forms of wind-based natural disturbance that have affected Massachusetts forests for thousands of years, commercial timber harvest plays a different role. Its frequency and distribution vary with respect to social variables, including distance to Boston and the proportion of a town that is forested. The proportion of a town's private forest that is harvested is influenced by a town's relative affluence. These social factors (e.g., distance to an urban center and relative affluence) have strong resulting effects on the ecology of forests, as well as their management for commercial purposes. Since regionally, harvest is a major factor related to tree mortality, it is important to identify factors that influence its likelihood. While this analysis is based on 30 yr of commercial harvest data in Massachusetts, it is likely that similar effects may be found radiating from other northeastern urban areas surrounded by forest, especially where the forest is primarily in private ownership. These results suggest that a given hectare of forest in a Massachusetts town will have a variable probability of harvest depending on a variety of non-ecological factors (e.g., distance to Boston, community affluence, public or private ownership). The relative amount of forest in a town is an important biophysical factor.

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SUPPORTING INFORMATION

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