Landscape and Urban Planning 177 (2018) 64–74

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Using public participatory mapping to inform general land use planning and zoning

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ARTICLE INFO

Keywords:
Zoning
General plan
Participatory mapping
PPGIS
VGI

ABSTRACT

Zoning is a ubiquitous land use planning and regulatory mechanism whose purpose is to provide for orderly community growth and development by segregating land uses that are deemed incompatible. The delineation of zones and related land use ordinances are traditional components of an expert-driven, local government process that produces a *general* or *comprehensive* land use plan as required by law. Public participation in the development of general land use plans has rarely used participatory mapping methods that engage the general public to explicitly inform zoning decisions. In this study, we demonstrate how participatory mapping methods can assess the consistency, compatibility, and potential conflict of zoning with public values and preferences in a general plan revision process using a coastal community in California as a case study. We describe the participatory mapping design, data collection, and data analyses in a workflow to illustrate the methods, and present the strengths and limitations of the approach for use in a general land use planning process. Future research should expand these methods to assess the potential effects of resident domicile and "NIMBYism" on the results, and importantly, assess the impact of public participatory mapping in land use decisions if actually implemented by local government authorities.

1. Introduction

Zoning is a ubiquitous land use planning and regulatory mechanism whose purpose is to provide for orderly community growth and development by segregating land uses that are deemed incompatible. Zoning seeks to prevent new development from interfering with existing uses and to preserve community "character", but is also used to implement government plans and policies related to economic development and urban renewal. There are a variety of zoning systems with Euclidean zoning (named after Euclid, Ohio) being the dominant system in North America. In Euclidean zoning, parcels of land are spatially delineated and accompanied by land use ordinances that identify allowable and/or conditional land uses. Typically, local zoning boards provide a mechanism by which property owners can seek variances to the zoning regulations. The use of zoning in the U.S. to regulate private property is a constitutionality valid use of state government police power (Village of Euclid v. Ambler Realty Co., 1926) provided it is not arbitrary and is reasonably related to public health, safety, comfort, morals, and general welfare.

A prominent critique of Euclidean zoning by Jacobs (1961) characterized it as contributing to the decay of municipal infrastructure and social capital, resulting in cycles of poverty in New York City. This early critique of zoning has since expanded to include a wider range of problems including environmental externalities associated with urban sprawl (e.g., pollution, loss of farmland), racial and socioeconomic segregation, and general reduction in quality of life (Hall, 2006; Rothwell & Massey, 2009; Wickersham, 2000). And yet, approximately ninety-seven percent of incorporated cities in the U.S. use zoning to regulate land use (Dietderich, 1996).

Zoning consists of two components—a spatial area defining the zone and the regulations that apply to land use within the zone. A zoning map is an outcome of the initial development or revision of urban and regional plans, commonly called *general* or *comprehensive* land use plans. The writing and revision of land use ordinances for the zoning categories (e.g., residential, commercial) may or may not be tightly coupled with the general planning process. The combination of the zoning map and ordinances provide the legal and enforceable land use regulations needed to carry out the general plan policies identified by the local government authority.

The focus of this study is on information and methods that can be

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https://doi.org/10.1016/j.landurbplan.2018.04.011
Received 11 January 2018; Received in revised form 21 March 2018; Accepted 28 April 2018

used to identify spatial areas that are compatible (or not) with the intended purpose of the land use zoning categories. Although we apply the methods to a U.S. general planning process, the methods and principles can be applied to other planning systems where spatial zoning is used to achieve land use objectives. A participatory mapping process, when carefully designed using representative population sampling and unbiased spatial attributes, may be broadly conceived as assessing the social acceptability of current and/or future land use while providing diagnostic evidence that land use change may be needed. The systematic assessment of the social acceptability of zones in a general land use plan is rare because zoning typically manifests as a top-down, expert-driven process administered by local governments with the assistance of professional planning staff. In general, the spatial delineation of zones in a general plan express local government aspirations for current and future development, subject to constraints imposed by the physical environment (e.g., topography, hazards) or higher level government authorities (e.g., regional or state government mandates). Whether local government leaders, through democratic elections, reflect the social acceptability of land uses identified through general plan zoning is a matter of debate. Regardless, zoning is the outcome of both a socio-political process (determination of future community goals related to land use) and technical feasibility process (i.e., the physical characteristics of the land to support the desired land uses). As observed by Steele (1986), although zoning is a legal process, the rules serve to trigger sociopolitical processes as much as they serve as substantive norms to be enforced.

1.1. Participatory mapping, planning, and zoning

Participatory mapping is a type of public participation that includes the generation and/or use of spatial information for a variety of purposes. Participatory mapping is highly variable in design and implementation and is described by the terms public participation GIS (PPGIS), participatory GIS (PGIS), and volunteered geographic information (VGI). Participatory mapping has experienced significant growth in applications, publications, workshops, and conferences over the last decade (see Brown & Kyttä, 2014, 2018; Dorning, Van Berkel, & Semmens, 2017; Mukherjee, 2015).

Participatory mapping, when applied to land use planning, may be considered a type of planning support system (PSS) (see Geertman & Stillwell, 2009; Geertman & Stillwell, 2012) with an emphasis on the participatory component of the system. As a form of public participation, participatory mapping shares many aspirational goals of general public participation such as increasing trust, reducing conflict, informing and educating the public, incorporating public values into decision making, and improving the quality and legitimacy of decisions (Bierle, 1999; National Research Council., 2008). To date, there is little evidence that new spatial technologies and digital media platforms that are increasingly used in participatory mapping have significantly advanced public participation outcomes towards these aspirational goals. To address one weakness in public participation for general land planning—lack of broader public engagement—some researchers have argued for greater use of crowdsourcing to maximize and diversify stakeholder input (Brabham, 2009; Brown, 2015). However, this would require more *active* participant recruitment for engaging in planning processes rather than the prevailing *passive* approach where the public is simply provided an "opportunity to comment" on a draft plan as required by law.

Although participatory mapping is acknowledged to have significant potential to inform a wide range of planning system support applications (Kahila-Tani, Broberg, Kyttä, and Tyger, 2016), there are few published studies where participatory mapping has been applied as a potential means to inform zoning decisions for urban or regional planning processes.

1.2. Zoning consistency, conflict, and compatibility analyses

Within the field of participatory mapping, various descriptive terms have been used to characterize the relationship between participatory mapped attributes and the existing or intended land use. The terms *consistency*, *conflict*, and *compatibility* are related descriptors but have been operationalized differently with participatory mapped data. The term *consistency* describes the situation where the distribution of participatory mapped attributes (e.g., place values or land use preferences) show a significant association (i.e., are not independent) with land use and further, that the proportion of the different mapped attributes appear logically related (e.g., a higher proportion of residential preferences are mapped in areas of residential land use). The consistency of the mapped data with current or proposed land use can be implemented and interpreted with chi-square/residuals analyses where spatial data are collected as frequencies. To date, consistency analysis has not been systematically applied to zoning decisions in a comprehensive land use planning process.

The term *conflict*, or more accurately, *conflict potential* in participatory mapping describes the situation where opposing preferences for land use are mapped in the same geographic location. Conflict potential is conceptually grounded in a two factor model based on the level of mapped agreement or disagreement for a given land use as well as place importance (Brown & Raymond, 2014). Multiple conflict potential indices can be operationalized that describe the potential for conflict using mapped land use preferences, place values, or a combination of these attributes. Conflict potential analysis has been applied to residential and tourism development (Brown & Raymond, 2014), urban densification (Kahila-Tani et al., 2016), and a wide range of natural resource land uses such as mining, tourism, forestry, recreation, and nature protection (Brown, Kangas, Juutinen, & Tolvanen, 2017; Hausner, Brown, & Lægreid, 2015; Moore, Brown, Kobryn, & Strickland-Munro, 2017). However, conflict analysis has not been systematically applied to zoning decisions in a comprehensive land use planning process.

The term *compatibility* refers to the situation where mapped attributes appear well-suited to the existing or intended land use for the area. The most critical step in compatibility analysis is a determination about the perceived compatibility between the mapped spatial attribute and the land use. When multiple spatial attributes are mapped (e.g., place values such as scenic and recreation) across multiple potential land uses (e.g., residential development, open space), a matrix will describe the perceived pairwise relationships (e.g., Y = compatible, N = incompatible, M = maybe compatible). Compatibility assessments can be made by individual analysts, members of a planning team, or individuals not directly involved in the planning process. Compatibility analysis, to date, has not been applied to zoning in general or comprehensive land use plans.

Consistency, conflict, and compatibility analyses can be conducted independently or in sequence to provide planning support. Consistency and conflict potential analyses appear most useful as diagnostic planning tools while compatibility analysis has greater potential to inform zoning decisions. Consistency analysis is a useful first step to evaluate the quality of the participatory mapped data and to identify focal areas for further analysis. For example, there may be a logical and valid reason why participants map more preferences for residential development in a commercially zoned area, but additional information and/or analyses will be required to understand why. Conflict potential analysis is useful to identify specific geographic areas where the potential for conflict is high for specific land uses that may correspond to zoning areas. Compatibility analysis is the most complex because it is multi-variate and involves judgments about the selection of the compatibility model, the model inputs, and thresholds in model outputs that are linked to zoning decisions. Further, compatibility analysis requires careful review of the land use ordinances that identify allowable and conditional land uses in the zones. These ordinances provide far more

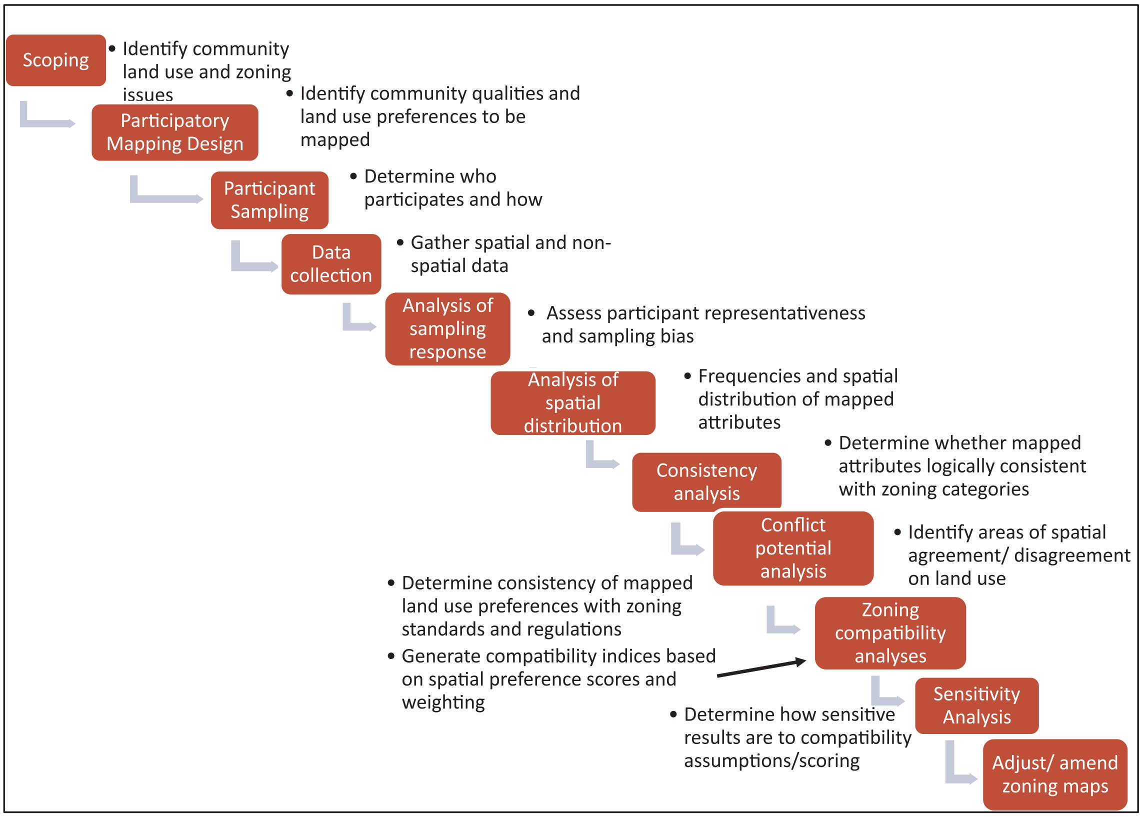


Fig. 1. Workflow for implementing participatory mapping into Avila Beach Community Plan revision.

specific and comprehensive coverage of potential land uses that must be subjectively interpreted and generalized to assess compatibility with mapped attributes. Sensitivity analysis is an important addition to compatibility analysis because it evaluates how compatibility assessment outcomes may be influenced by compatibility model assumptions. In this article, we present these three types of analyses (*consistency*, *conflict potential*, and *compatibility*) sequentially to demonstrate how social, spatial information can be applied to general plan zoning.

1.3. A process for applying participatory mapping to general plan zoning

We demonstrate the use of participatory mapping to inform general plan zoning using a case study from a community planning process in Avila Beach, California, that began in 2016. The Avila community provides a good example to illustrate the potential of participatory mapping to inform general plan zoning because it contains a diverse range of zones (called "land use categories") found in many general plans and is not overly complex because the community is relatively small in both area and population.

In Fig. 1, we provide an overview of the participatory mapping process and the sequential steps that were followed to collect and analyze the data. We follow this work flow sequence in the reporting of the methods and results in this paper. The work flow presents a logical sequence of data analyses, beginning with simple descriptive statistics of both participants and the mapped data in the zones, and then adds greater complexity through the addition of multiple land uses. The *consistency*, *conflict potential*, and *compatibility* analyses reported herein are not intended to be exhaustive, but rather illustrative of options for analyzing the data to inform zoning. Given the planning process for the revised Avila Community Plan is a multi-year process, we cannot evaluate whether the participatory mapping process actually influenced general plan outcomes. We do, however, discuss the findings of our analyses to describe how they could be used to inform zoning in the general plan.

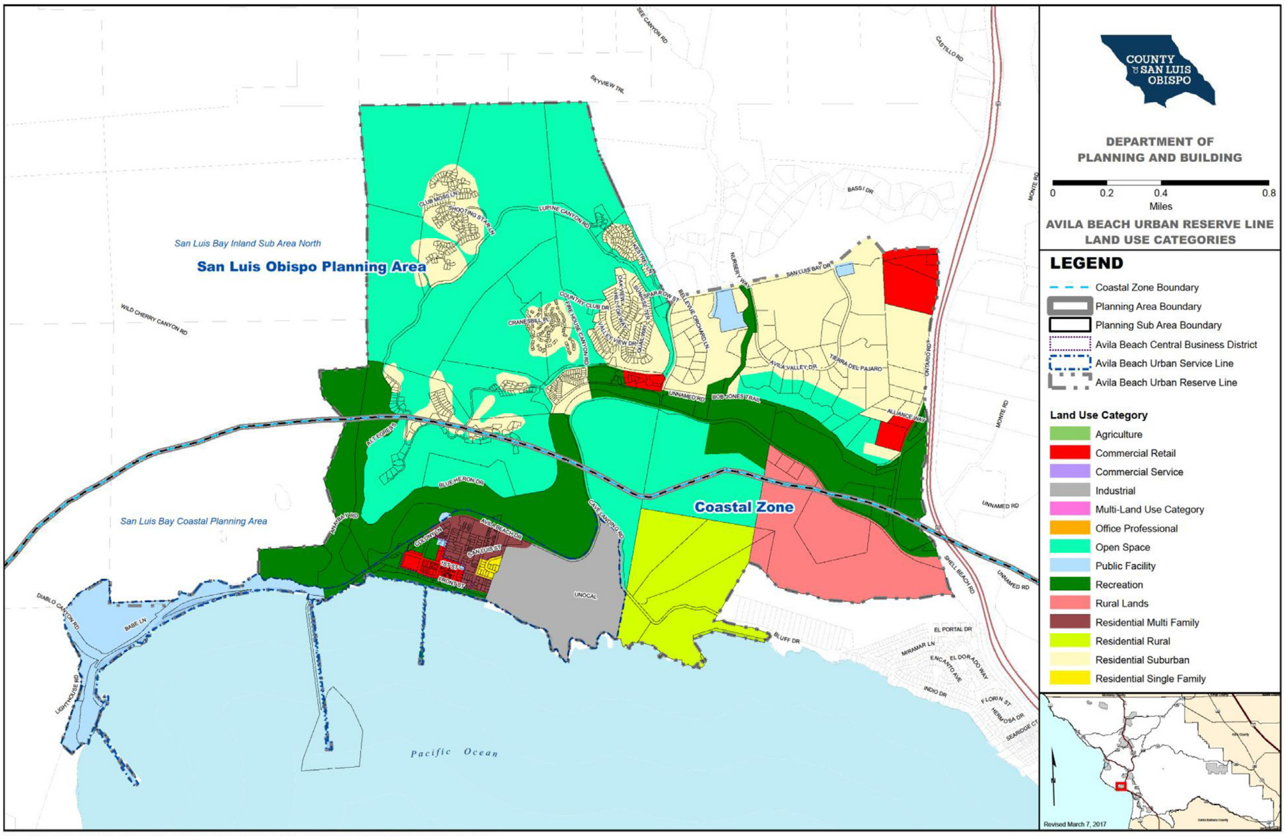
As a planning methods paper, our primary focus is to demonstrate the potential of participatory mapping in support of general plan zoning and to identify the strengths and weaknesses of the methods involved. Most general and comprehensive planning processes will involve some unique circumstances relating to the planning area and the people involved. Where possible, we attempt to generalize the results rather than focus on results that appear specific to the Avila community planning process. As such, this paper is intended to provide a general protocol for designing and implementing a participatory mapping process in the initial stages of a general or comprehensive plan revision.

2. Methods

2.1. Study area

Avila Beach is an unincorporated coastal community (Census Designated Place or CDP) located in San Luis Obispo County, California, U.S., with an estimated population of 1474 in 2015 (SLOCOG, 2017). The area was the historical home of the Chumash Native Americans with Spanish occupancy increasing in the late 18th century associated with Spanish missionaries. The area has served as the principle port for the region with multiple piers for commercial fishing and oil transport. In 1906, Union Oil Company built an oil tank farm on 95 acres near the town site which eventually leaked from corroding pipes under the town. Following a large financial settlement and extensive remediation effort beginning in the 1990's, many homes and businesses were razed and rebuilt, leaving few historical buildings. In modern day Avila, tourism is the community's primary economic activity despite the continued presence of a commercial fishing pier, research pier (Cal Poly University), and surrounding agricultural activity.

The specific focus of this case study is the land area encompassed within Avila Urban Reserve Line (see Fig. 2) containing just over 2220 acres. Land use within this area is governed by four primary plans: San Luis Obispo Inland Area Plan, Avila Community Plan (Inland), San Luis



Sources: County of San Luis Obispo, Department of Planning and Building, ParcelQuest, USGS National Hydrography Dataset, California Department of Finance

Fig. 2. Avila Beach planning area with current land use categories.

Bay Area Plan (Coastal), and the Avila Beach Specific Plan. Of relevance to this study are the land use categories (i.e., zones) described in the plans. The largest area is zoned Open Space at 38%, followed by Residential Suburban at 19%, and Recreation at 18%.

2.2. Sampling and data collection

In 2017, we designed and implemented an internet-based PPGIS survey as one component of the public participation process for the Avila Community Plan update. The survey website used a Google® maps application programming interface (API) where participants were instructed to drag and drop digital markers (icons) representing different place values and land use preferences onto a map of the planning area (Avila Urban Reserve Line). The mapping interface consisted of three "tab" panels containing digital markers for eight place values (panel 1) and 10 preferences favoring a particular land use such as residential development (panel 2), or opposing the same land use (panel 3). Participants were asked to mark different locations on the map with specific icons to indicate place values, as well as locations where they preferred (or not preferred) specific land uses. The survey also included text-based questions to collect participant characteristics (demographics) such as home location, age, gender, education, family structure, and how they learned about the study and a set of community planning questions that asked participants about appropriate levels community development such as residential and tourism development, parking, community events, and environmental protection. Thus, the survey contained both spatial and non-spatial variables.

The sampling frame for primary data collection was the county's property parcel database. A total of 820 unique parcels were identified in the planning area and owners of these parcels were mailed a letter of invitation (henceforth referred to as the "household" sample). Of these parcels, about 85 were associated with business or corporation names. The recruitment letter identified the purpose of the survey—to inform the Avila Community Plan update—while providing survey instructions, the URL for the PPGIS website, and a unique access code to track participant responses. About two weeks after mailing the recruitment letter, a reminder postcard was sent to non-participants to encourage participation. The survey website allowed individuals that did not receive an access code to also participate and this group is referred to as the "volunteer" sample. Data collection occurred from February through March 2017.

To accommodate potential participants less comfortable with internet technology, a mapping "office hours" was held at the Avila Community Center to assist anyone wishing to participant in the survey, but felt they wanted additional support. The survey website included "how-to" video posted to help guide participants through the mapping process. Two individuals participated in the survey at the community center and 93 individuals viewed the on-line "how-to" tutorial video.

2.3. Analysis of mapping behavior and participant profile

We analyzed mapping behavior (number and type of markers) and participant characteristics by sampling group (household vs. volunteer) and residential status (full-time resident, part-time resident, and non-resident). We compared participants with comparable census data for Avila Beach on the variables of age, gender, education, and lifecycle state to assess the extent of sampling bias in survey response. We cross-tabulated sampling groups by place value categories and development preferences (supporting/opposing) to generate chi-square statistics and standardized residuals. The chi-square statistic indicates whether two nominal (categorical) variables appear independent or whether there is a statistical association. The larger the chi-square statistic, the greater the difference between the observed and expected number of value markers under the assumption of independence. Given that chi-square results for marker distributions are likely to be statistically significant, we generated standardized chi-square residuals to reveal which marker/sampling group pairs significantly contribute to the overall chi-square result. Residual values greater than +2.0 indicate there were significantly more markers than expected by sampling group while residual values less than −2.0 indicate there were significantly fewer value markers than expected.

2.4. Zoning consistency analysis

Consistency analysis examines whether the distribution of marker types by zoning category appear logically consistent (e.g., mapped open space markers in an area zoned for open space). To conduct mapping consistency analysis, we combined the mapped data for all participants and analyzed the distribution of mapped place values and land use preferences (supporting/opposing) by zones located in the planning area using chi-square statistics and standardized residuals. Following a significant chi-square statistical result, the standardized residuals indicate which marker types appear significantly under or over-represented by zoning category. Consistency analysis requires subjective interpretation about whether the distribution of mapped place values and land use preference appear "consistent" in the zoning category, and if not, to inquire further about the unexpected result. Residual values greater than +2.0 indicate significantly more markers of a given type than expected by zoning category while residual values less than −2.0 indicate significantly fewer value markers of that type than expected.

2.5. Zoning conflict potential analysis

There are many possible variations on assessing conflict potential for land use. To demonstrate some of the important issues in conflict potential mapping for zoning, we conducted conflict potential analyses with two different conflict potential indices at two spatial scales for four land uses (residential development, commercial development, tourism development, and parking). The calculation of alternative conflict potential indices are described by Karimi and Brown (2017). The preference score (PS) index measures the level of mapping agreement between supporting and opposing preferences for a given land use within the same geographic area. The index is computed as a ratio that varies between 0 (all preferences either support or oppose the land use indicating complete agreement) and 1 (preferences are evenly divided between supporting and opposing land uses indicating complete disagreement). The weighted preference index (WPS) weights the PS index by the number mapped preferences in the geographic area. The preference and value index (PVS) is the same as the WPS except preference ratios are weighted by the number of mapped place values in the same geographic area. Conflict potential indices convert counts of points or polygons to a continuous numeric scale with higher scores associated with higher conflict potential.

Consistent with previous conflict modeling studies, we used a sampling grid approach (fishnet) clipped to the planning area to calculate conflict index values per grid cell. The selection of grid cell size is a heuristic judgement based on the quantity of mapped data and the spatial scale that seems appropriate for assessing conflict potential. If the sampling grid cell size is too small, there are too few observations (points) in each cell and if the grid cell size is too large, the conflict maps provide insufficient spatial resolution for meaningful interpretation. We determined the best size for analysis would be a 50 m grid cell size based on the quantity of spatial data and fit with existing zoning areas. This generated 3834 grid cells for the study area. We calculated and mapped conflict potential scores for each cell using the WPS index.

We also calculated conflict potential using the PS index for seven unique zoning categories in the planning area that contained the largest quantities of mapped preferences. We labeled four classes of zones on the PS scale as low (0–0.10), medium low (0.10–0.25), medium high (0.25–0.50), and high (> 0.50). For visual comparison and to present some of the trade-offs in different conflict methods, we overlayed the grid-based indices (based on WPS) with the zone-based indices (based on PS index) to examine the spatial location of areas of high conflict potential within each zone. An alternative to the grid cell approach for visualization would be the use of point density maps.

2.6. Zoning compatibility analysis

Zoning compatibility assesses whether the rules regulating land uses within a given zone appear consistent with the preferences mapped by participants to determine whether the zoning category or the land use rules associated with the zone, merit change. Although compatibility analysis can focus on the compatibility of a single type of land use within a zone (e.g., residential development), compatibility analysis, as described herein, assesses multiple possible land uses within the zone. Thus, compatibility analysis adds complexity to conflict potential analysis by considering multiple land use preferences, and unlike conflict potential analysis, involves subjective interpretation about whether the preference markers appear consistent with the zoning rules.

We performed zoning compatibility analysis on the mapped data in a sequence of steps. We first identified zones in the planning area containing the largest quantity of mapped land use preference data for each type of zoning category and then selected the top seven zones for demonstration purposes. We then reviewed the land ordinances applicable to the planning area to determine whether the land use preference marker categories (e.g., residential development, open space) would be considered allowable uses in each of the seven zones. This step generates a compatibility assessment matrix with zones cross-tabulated by land use preference marker types. The assessment of compatibility of land use by zoning category requires subjective judgement because the land use preference markers in participatory mapping are generalized while the land use ordinances contain more specific land use options by zone. Further, the land use ordinances often have conditions applied to different types of land uses within the zones. Thus, there was not a simple one-to-one correspondence between a land use preference marker type from participatory mapping and the land uses identified in the ordinances. In this case study, there was a further complicating factor in that the planning area has a coastal zone overlay that places greater restrictions on some types of land uses within the same zoning category. For simplicity in illustration, the compatibility assessment did not include potential differences arising from the coastal zone overlay. We also chose not to include three preference marker categories (out of 10) in the compatibility assessment—road access, coastal access, and new trails. The road access marker category was specific to the Avila study and was intended to identify possible new road routes into the community which only has a single access road. The coastal access and trail location preference categories were also intended to identify possible new routes for trails. All three of these preference categories represent linear features that could be built with appropriate legal easements regardless of the underlying zoning category, and further, they would occupy a small percentage of the zoning area.

We assigned one of three compatibility outcomes to each marker/zone pairing based on interpretation of the land use ordinances: Y = largely compatible, N = largely incompatible, and C = conditionally compatible. This is called the zoning/land use compatibility matrix.

Land use preference	Zone		
	A	B	C
Residential	Y	Y	N
Commercial	N	C	Y
Open space	Y	N	C

The next step was to translate the categorical compatibility assessments

(Y, N, C) into a quantitative scoring system to indicate the relative compatibility of participant mapped preferences with the current zones. There are many possible options for scoring the assessment categories. For purposes of illustration, we choose the simple scoring system below. This matrix is called the zoning compatibility scoring matrix.

Allowed use	Preference (support)	Preference (oppose)
Yes (Y)	1	−1
No (N)	−1	1
Conditional (C)	.5	.5

The marker counts by zoning/land use category were then multiplied and aggregated within each of the zones to generate a total compatibility index score that could be either positive or negative depending on the distribution of markers in the zone. The final step was to interpret the compatibility indices by zone to determine whether the mapped preferences suggest that a change in zoning classification or changes in the land use ordinances may be warranted given public preferences for land use within the zone. The sign of the aggregate compatibility score indicates whether mapped preferences are overall compatible (+) or not (−) with the allowable land uses in the zone, while the magnitude of the compatibility score indicates the relative strength of compatibility across zoning categories.

After a compatibility score is calculated for each zone, the distribution of scores are examined to identify thresholds indicating where zoning changes may be warranted (or not). Large positive scores indicate a high level of compatibility suggesting no change, while large negative scores indicate low compatibility and possible areas for rezoning to increase the social acceptability of land use in the planning area. Compatibility scores that range between the high and low extremes require analyst judgement as to their planning significance, but can be aided by standard statistics describing the distribution of scores such as range, mean, and standard deviation, and by standardization and ranking to reduce the influence of the uneven distribution of preference markers mapped in the various zones.

Given that analyst judgement is involved in the calculation of zoning compatibility, an important step is to determine the sensitivity of the compatibility scoring outcomes to zoning compatibility judgments, including the scoring system used to calculate the scores. There are multiple approaches to sensitivity analysis and in this study, we performed sensitivity analysis by modifying the compatibility matrix (i.e., Y, N, C classification of preferences within the zoning categories) and by modifying the quantitative weights assigned to the compatibility judgements (+1, 0.5, −1). Specifically, we evaluated the sensitivity of compatibility scores by eliminating the “C” or conditional compatibility assessment and by varying the quantitative score assigned to the “C” category from 0.5 to 0.2.

The final step in our analysis was to examine the relationship between zoning compatibility scoring and the output of conflict potential analyses by calculating rank correlations between zone compatibility scores and aggregated conflict potential indices by zone. Specifically, we examined the extent to which land use conflict potential (differences in opinion about specific land uses in a zone) based exclusively on mapped preferences is related to the overall assessment about zoning compatibility which involves analyst judgement about allowable land uses within the zoning categories.

3. Results

3.1. Participation rates and sampling group analyses

A total of 174 individuals mapped one or more locations and of these, and 140 individuals completed the post-mapping survey questions (see Table 1). The response consisted of 141 households and 33 volunteers. The household survey response rate was estimated to be 21% after accounting for 149 non-deliverable recruitment letters. There were 7682 mapped locations, with the mean number of markers mapped (full completion) equal to 51 with a median value of 37. Participants mapped more land use preferences than place values, on average. In terms of demographics, participants were older (mean age 64 years), more male (57%), and had a higher level of formal education (88% with bachelor’s degree) than indicated by census statistics for the area. About 60% of participants were full-time Avila residents with about 30% part-time residents.

Given the potential bias associated with random household sampling versus volunteer sampling (Brown, 2017), we analyzed general mapping behavior by sampling group. There were no statistically significant mean differences (*t*-tests, $p > 0.05$) between the household

Table 1
Participant profile based on survey responses. Selected census demographics are provided for comparison from the 2011–2015 American Community Survey 5-Year estimates for Avila Community. Not all percentages total 100% due to rounding.

Mapping behavior	All	Household	Volunteer
Number of participants (mapped one or more locations)	174	141	33
Number completing post-mapping survey	140	128	12
Number of locations mapped (w/full completion)	7189	6287	902
Number of locations mapped (w/partial completion)	7682	6602	1080
Range of markers mapped (min/max full completion)	1–327	1–327	1–279
Mean (median) all markers mapped	51 (37)	49 (37)	75 (45)
Mean (median) place values mapped	21 (14)	20 (13)	29 (35)
Mean (median) preferences mapped (acceptable)	25 (17)	22 (16)	57 (43)
Mean (median) preferences mapped (not acceptable)	19 (11)	19 (11)	20 (9)
Knowledge of study area	**All**	**Household**	**Volunteer**
Knowledge of places (%)[1]			
Excellent	48%	46%	67%
Good	39%	41%	17%
Average	12%	12%	17%
Below average	1%	1%	0%
Poor	0%	0%	0%
Residence	**All**	**Household**	**Volunteer**
Full-time resident	58%	58%	58%
Non-resident	13%	11%	33%
Part-time resident	29%	31%	8%
Years lived in Avila (mean, full-time residents)	13	14	11
Demographics			
Gender (ACS 2015: Male 54.3%)[1]			
Female (%)	42.4%	42.5%	41.7%
Male (%)	57.6%	57.5%	58.3%
Age in years (mean/median) (ACS 2015: median 58.5)[1]	64/65	64/65	64/67
Education (%) (ACS 2015: 45.5% Bachelors/postgraduate)[1]			
Less than Bachelors	12.5%	12%	18%
Bachelor’s degree/postgraduate	87.5%	88%	82%
Lifecycle Stage[1]			
Mature Couple/No children	18%	17%	25%
Mature Single	10%	8%	10%
Mature Family (youngest child over 16)	17%	17%	17%
Middle Family (youngest child 6–15 years old)	4%	5%	0%
Older Couple (no children living at home)	42%	44%	0%
Young Family (youngest child less than 6 years old)	2%	2. %	0%
Young Single	1%	1%	8%

[1] Difference between household and volunteer samples not statistically significant.

and volunteer sampling groups on total markers mapped (mean household = 49, volunteer = 75), but there was a difference in the mean number of land use preference markers (mean household = 43, volunteer = 94). This difference can be attributed to a small number of volunteer participants (n = 3) that mapped a higher number of land use preferences. Because the mean number of markers can be influenced by greater mapping effort by a few participants, we also examined the general propensity of participants in the two sampling groups to map values or preferences based on the proportion of individuals within each group that placed one or more markers. We found no statistically significant differences in mapping propensity for general marker categories (place values or preferences) by sampling group (chi-square tests, $p > 0.05$). In summary, there were more similarities than differences in the mapping behavior of the two sampling groups (household vs. volunteer), with the quantitative differences in mapping behavior being small.

We examined whether there was a significant association between sampling group (household vs. volunteer), resident status (full-time, part-time, and non-resident), and the types of place values mapped. There was a weak, but significant association between sampling group and place values ($X^2 = 78.5$, df = 7, $p < 0.001$; Cramer's V = 0.17, $p < 0.001$). Based on standardized residuals, the household group mapped proportionately more *recreation* (std. residual = +2.0), *natural* (+2.0), *social* (+2.3), and *favorite place* values (+4.6), and fewer *scenic* values (−7.7) than the volunteer group. There was an even weaker association between resident status and place values ($X^2 = 57.9$, df = 14, $p < 0.001$; Cramer's V = 0.11, $p < 0.001$). Non-residents mapped proportionately more *economic* values (std. residual = +6.3) and fewer *natural* values (−2.1) and favorite places (−2.9). Overall, these results indicate relatively small differences in the place values identified and mapped by sampling group.

There were stronger associations between sampling group, resident status, and mapped land use preferences. Volunteer participants mapped more preferences for open space (std. residual = +7.3) and trails (+7.0), while household participants mapped more opposing preferences for residential development (+8.1), tourism development (+3.6), commercial development (+2.9), and other development (+2.2). Non-residents mapped more preferences for most types of built development than residents such as residential, tourism, and commercial development. Consistent with this finding, residents mapped more preferences opposing most types of new built development. Overall, those participants living in Avila Beach expressed proportionately more land use preferences in opposition to new built development while those participants living outside the community expressed more support for built development. Residents mapped more supporting preferences for open space but fewer supporting preferences for trails than non-residents.

3.2. Consistency analysis

We examined whether the distribution of marker types by zoning category were logically consistent using chi-square/residuals analysis. There was a moderate association between the distribution of place values by zoning classification ($X^2 = 810.9$, df = 48, $p < 0.001$; Cramer's V = 0.24, $p < 0.001$). The majority of pair-wise chi-square residuals indicate logical consistency between community place values and the zoning category. For example, *economic* value was mapped significantly higher than expected in the commercial/retail zone (std. residual = +15.0) and significantly lower in other zones such as open space (−4.9), recreation (−3.7), and residential zones. *Social* values were also mapped significantly more in the commercial/retail zone (+8.6) and significantly less in open space (−4.1). The one zoning category where the results do not appear logically consistent is the area zoned for industrial use. *Natural* (+3.8) and *scenic* (+3.9) values would not normally be associated with industrial zones in most geographic locations, yet these values were mapped more frequently than expected in the Avila industrial zone. Why? The explanation is found in the specific history and setting of the industrial zone which is an abandoned fuel tank farm situated on a scenic bluff overlooking the coast. Although there is visual evidence of industrial activity, much of the site today is open with natural vegetation.

The spatial distribution of land use preference markers were significantly associated with *supporting* preferences ($X^2 = 1786.3$, df = 72, $p < 0.001$; Cramer's V = 0.295, $p < 0.001$) and *opposing* preferences ($X^2 = 43.8$, df = 48, $p < 0.001$; Cramer's V = 0.20, $p < 0.001$). The majority of pair-wise significant chi-square residuals indicate logical consistency of the mapped preference with the existing zoning categories. For example, preferences supporting commercial/retail (std. residual = +11.8), tourism (+7.0), and parking (+5.3) land uses were mapped significantly more than expected in the commercial/retail zone, open space preferences were mapped significantly more in the open space zone (+24.2), and residential development preferences were mapped significantly more in the residential multi-family (+18.4) and residential suburb zones (+11.9).

Preferences opposing the various land uses by zoning categories indicate those zones where participants likely appear concerned about current uses in the zones. For example, preferences opposing parking use were significantly higher than expected in the commercial/retail zone (+4.8) while preferences for no development of any type were significantly greater than expected in the commercial/retail zone (+2.4), residential suburb zone (+4.0), and rural lands zone (+2.4). Additional parking also appears to be a major concern for the residential multi-family zone (+10.1). The area zoned for industrial use (former fuel tank farm) had significantly more opposing tourism (+4.7) and commercial (+4.1) preferences than expected, and consistent with the mapped place values, indicate that land use for this area warrants special planning attention. One other relationship appears deserving of special attention. The number of opposing preferences for holding events in areas zoned "recreation" was significantly higher than expected (+7.5). The Avila Beach community has become an important destination for regional special events that impact local residents in the locations where the events are held.

3.3. Conflict potential analysis

We mapped conflict potential for four land uses in the seven zones with the largest number of mapped preferences using the preferences score (PS) index. The PS index calculates the ratio of supporting to opposing mapped preferences on a scale from 0 to 1 and does not consider the absolute number of preference markers mapped in the zone. The PS indices were categorized into four categories ranging from low to high conflict potential and color-coded for each zone. The results are presented visually in Fig. 3.

The highest conflict potential for residential development was found in the area currently zoned industrial (IND), followed by the smaller commercial/retail zone (CR). There is relatively little conflict potential in the open space (OS) and public facilities (PF) zones with participants agreeing that residential development is not appropriate in these zones. For commercial land use, the greatest conflict potential was in the public facilities (PF) zone. This beach and port area receives significant recreational day use with participants more divided—based on mapped preferences—about whether to allow more commercial activity in this zone. The greatest conflict potential for new tourism development was found in the industrial (IND) and rural residential (RR) zones with low conflict potential in the open space (OS), commercial/retail (CR), and public facilities (PF) zones. The highest potential conflict for parking land use was in the recreation (REC) zone that is adjacent to the commercial/retail (CR) and public facilities (PF) zones. This elongated stretch of parklands that is zoned REC is the site of multiple special events and is also within walking distance to the central commercial/retail area. The open space (OS) zone also indicates high conflict potential for parking land use, with a PS index value of (0.75). However,

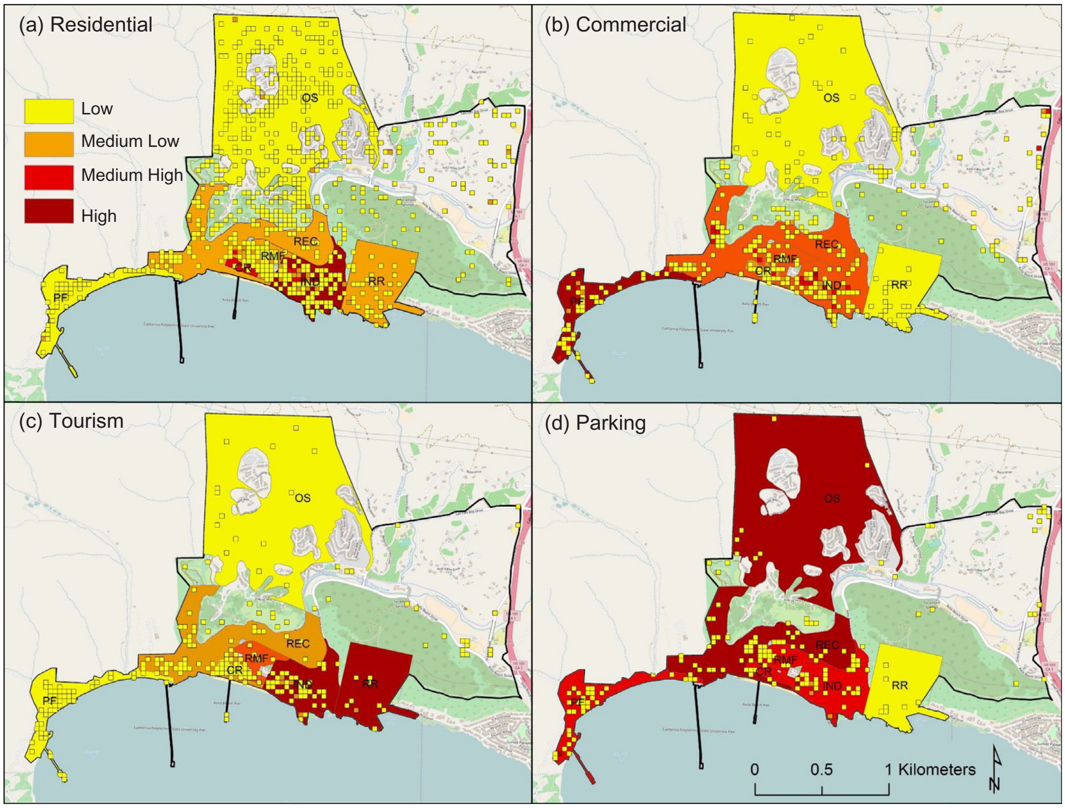


Fig. 3. Conflict potential maps for four land uses: (a) residential, (b) commercial, (c) tourism, (d) parking in seven unique zoning categories with the largest amount of point data. Conflict potential index is shown at two scales: by zoning category and 50 m grid cell. The seven land use zones are: RR (residential rural), RMF (residential multi-family), CR (commercial/retail), IND (industrial), REC (recreation), OS (open space), and PF (public facilities).

this specific result highlights one of the limitations of relying on a single conflict potential index because the high conflict potential is based on only a few parking preference markers (n = 7) mapped in the open space (OS) zone. Weighting these results by the number of mapped preferences in the zone (i.e., using the WPS rather than the PS index) would show relatively low conflict potential for the zone compared to the recreation (REC) zone which had 55 mapped parking preferences.

When conflict potential is visually mapped at a larger scale (50 m grid cells), one can see that conflict potential within the zone is often the result of point clustering within the zone. Alternatively stated, higher conflict potential for the whole zone can be driven by a smaller number of more specific locations within the zone containing many opposing land use preferences. For example, the conflict potential for residential development and parking in the recreation zone (REC) is being driven by the large number of residential and parking preferences that were mapped proximate to the commercial/retail area in the community.

The current industrial (IND) zone, the site of a former fuel tank farm, merits special attention. For the four land uses analyzed (residential, commercial, tourism, and parking), this zone consistently indicates high conflict potential (medium high or high) at both the whole zone and 50 m grid scales. This zone had the largest number of mapped preferences (n = 926) of all seven zones and revealed the highest participant disagreement about future land use. This result is not surprising given that this area is unlikely to be used for future industrial activity and is thus subject to multiple competing visions for the area, ranging from conservation/protection to redevelopment.

3.4. Compatibility analysis

Compatibility scores for each of the seven zones were calculated based on different model parameters and appear in Table 2. Using the (Y, C, N) compatibility assessments and assigned scores of (+1, 0.5, −1), the highest compatibility score was for the open space (OS) zone (450) and the lowest compatibility score was for the industrial (IND) zone (−102.5). The compatibility scores for the industrial zone were strongly influenced by the large number of mapped supporting preferences for open space, recreation, and residential land use that were judged as incompatible with the industrial (IND) zone category. In contrast, a high level of compatibility was found in the open space (OS) zone, the result of a large number of mapped open space preferences (supporting) and residential development preferences (opposing). The only other zone with a negative compatibility score was the residential rural (RR) zone, an outcome influenced by mapped preferences for open space (supporting) and residential development (opposing). The raw compatibility scores, ranging from −102.5 to 450, were standardized on a scale from 0 (highly incompatible) to 1 (high compatible) and heuristically labeled as follows: 0 to 0.3 (highly incompatible), 0.3 to 0.7 (compatible), and 0.7 and above (highly compatible).

In a demonstration of sensitivity analysis, the compatibility scoring outcomes were relatively insensitive to mapped land use preferences judged to be conditionally acceptable (C) in the zoning category, either by changing the conditional weight from 0.5 to 0.2 or by not scoring conditional preferences at all. The compatibility scores and ranks remained unchanged across the seven zones.

The rank correlations between zone compatibility scores and aggregated conflict indices for the seven land use preferences in the zones were negative and relatively weak for both the WPS (r = −0.28) and PS (r = −0.39) conflict potential indices. Higher zoning compatibility scores were correlated with lower conflict potential scores as expected given the operational calculation of the indices. Zoning compatibility scores were also moderately negatively correlated (r = −0.37) with the overall diversity of mapped preferences in the zones. Lower compatibility scores were associated with greater diversity in mapped

Table 2

Results of compatibility analysis (green), conflict potential analysis (pink), Shannon diversity index of land use preferences (blue), and confidence level based on number of participants mapping one or markers in the zone (orange). General conclusion about the compatibility of mapped land use preferences with the zoning category are indicated in yellow.

	Zoning Category								
	Commercial/ retail (CR)	Residential mult-family (RMF)	Industrial (IND)	Public facilities (PF)	Residential rural (RR)	Recreation (REC)	Open space (OS)	Mean	Std. Dev.
Raw compatibility scores (Y,N,C) with (+1, 0.5, -1)	89.5	70	-102.5	219.5	-80	284	450	132.9	198.9
Standardized (0 to 1)	0.35	0.31	0	0.58	0.04	0.70	1		
Rank (1 to 7)	4	5	7	3	6	2	1		
Compatibility scores (Y,N,C) and (+1, 0.2, -1)	82.6	70	-141.8	159.8	-96.2	224.6	449.4	106.9	199.6
Rank	4	5	7	3	6	2	1		
Raw compatibility scores (Y,N) and (+1, -1)	78	70	-168	120	-107	185	449	89.6	202.0
Rank (1 to 7)	4	5	7	3	6	2	1		
Compatibility Interpretation	Compatible	Compatible	Highly incompatible	Compatible	Highly Incompatible	Highly compatible	Highly compatible		
Aggregate conflict WPS	26.4	34.6	224.7	112.9	21.6	149.3	18.9	84.1	80.4
Aggregate conflict WPS (Rank)	5	4	1	3	6	2	7		
Aggregate conflict PS	1.0	1.4	2.6	2.4	1.1	2.2	0.9	1.6	0.7
Aggregate conflict PS (Rank)	6	4	1	2	5	3	7		
Shannon diversity index: normalized (0 to 1) with 1=more diverse	0.71	0.66	0.82	0.83	0.71	0.88	0.49		
Shannon diversity index (rank)	5	6	3	2	4	1	7		
Number of participants placing one or more markers	89	51	123	109	94	148	70		
Confidence level (rank)	5	7	2	3	4	1	6		

preferences within the zones.

4. Discussion

In this study, we described how participatory mapping can inform zoning decisions in a general land use planning process. A well-designed participatory mapping process can expand and enhance public participation to assess the social acceptability of current and prospective land use zones. In this discussion, we reflect on the strengths and limitations of participatory mapping to inform land use planning and zoning decisions in urban and regional planning contexts. We organize this discussion around three key themes: (1) the representativeness of community values and preferences, (2) the quality and validity of the spatial data collected for zoning decision support, and (3) the integration of crowd-sourced data within a technical and socio-political system that prescribes and regulates community land use.

4.1. Representativeness of community values and preferences

Sampling and participant recruitment should be designed to achieve full geographic coverage for the planning area and the populations impacted by zoning. There is empirical evidence that household sampling produces somewhat higher spatial data quality than volunteer sampling and that participant domicile affects mapped results through spatial discounting (Brown, 2017), i.e., participants tend to map closer to home based on both place familiarity and salience. Given this behavioral propensity, passive recruitment for public participation in a general land use planning process is unlikely to achieve community representativeness for zoning decision support. There is also evidence that mapping participants, even with active recruitment and systematic household sampling, will likely be biased toward older, more highly educated, and less socio-demographically diverse participants (Brown & Kyttä, 2014). Further, the resident status of participants can also influence what types of values and preferences are mapped, as evident in this study and other regional studies (Munro, Pearce, Brown, Kobryn, & Moore, 2017).

In light of these methodological limitations in sampling, what should be done to address the sampling limitations in participatory mapping? There is no panacea, but we suggest that participatory mapping include systematic household sampling as one public participation component, provide a range of mapping methods (e.g., hardcopy vs. digital) if feasible, and the number of participants be as large as possible to maximize the quantity of spatial data for analysis. In the illustrated case study herein, we consider the participation rate of about 21% of households to be acceptable, but on the margin for zoning decision support. Although not assessed in this study given the small study area, the spatial representativeness of participants would be important for larger urban and regional applications because of the phenomenon of geographic discounting. In the absence of spatial representativeness of participants by domicile, the mapped data will also not likely be spatially representative of the planning area. To provide an assessment of relative quality of participatory mapped data for decision support, Karimi and Brown (2017) proposed the idea of associating confidence levels with mapped spatial data based on the number of participants that mapped in a given area. In Fig. 4d, we show confidence levels associated with the zones (rankings) based on the number of participants that mapped in each zone. The highest levels of confidence in the mapped results were associated with the recreation (REC), industrial (IND), residential rural (RR) zones. Given the high potential for conflict, low zoning compatibility scores, and the high confidence level associated with the industrial (IND) zone, this zone is the strongest candidate for change in the revised Avila land use plan.

4.2. Quality and validity of the spatial data collected for zoning decision support

Data quality and validity for participatory mapping are closely related to sampling methods and outcomes, but also include spatial considerations. The quality and validity of participatory mapped data can be evaluated based on the spatial accuracy of mapped attributes, termed *validity-as-accuracy,* or evaluated based on the reputation, trustworthiness, and motivations of the spatial data contributor, termed *validity-as-credibility* (see Spielman, 2014). Brown, Weber, and de Bie (2014) argue that given the typical subjective nature of participatory mapping variables such as community values and land use preferences, *validity-as-credibility* appears more relevant to assessing the quality of the data. In this study, both validity perspectives appear relevant. *Validity-as-credibility* was partially assessed by examining the demographic characteristics of the participants (e.g., length of residence, knowledge of the study area), but would benefit from better understanding the

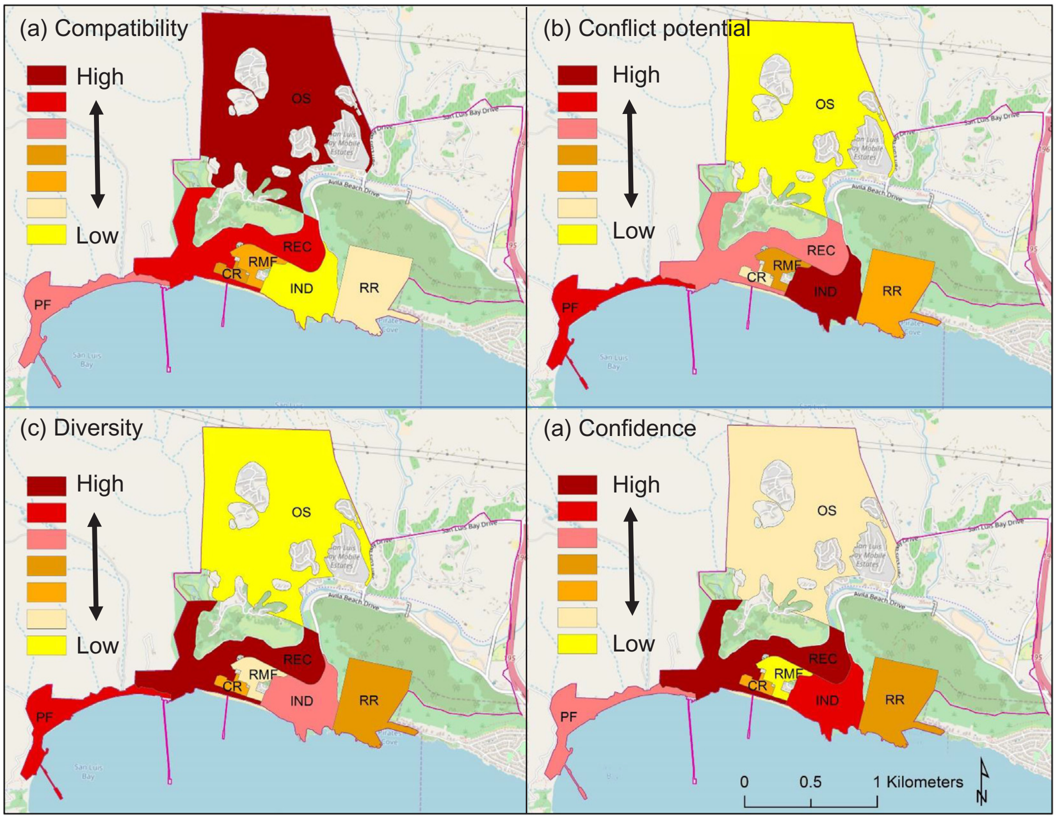


Fig. 4. Maps for seven different types of zones showing: (a) compatibility score based on seven mapped preferences being judged allowed (+1), not allowed (−1), or conditional (0.5) within the zoning category; (b) conflict potential scoring based on aggregated PS conflict indices; (c) normalized Shannon diversity scores for mapped preferences; and (d) confidence intervals for zones based on the number of participants mapping in each zone.

experiences and motivations of participants collected as non-spatial survey variables. These variables were not included in the case study survey instrument.

Spatial or locational accuracy in the placement of markers (*validity-as-accuracy*) was aided by providing participants the ability to zoom for higher spatial resolution, by providing easy map navigation tools, and by providing multiple digital map views (road, satellite, and terrain) allowing participants to locate specific landscape features in the study area. An important design consideration was whether to provide the planning area zoning map as an overlay which could influence what was mapped in various locations. In this study, the zoning map was not provided as an overlay and participants were not explicitly informed that the spatial data could be used to support zoning decisions. In the absence of experimental design, it is not possible to know how providing the zoning map might influence the placement of markers, especially land use preferences. An alternative mapping design would be to have participants assign or tag attributes to existing zones shown on the digital map rather than placing the markers in the planning area without visual reference to the zoning map. This tagging of attributes to zones would increase the spatial accuracy of marker attribution to zones, especially markers in boundary areas, but this benefit may be offset by the potential for confirmation bias wherein the participant is unduly influenced by zoning status quo rather than mapping preferences based on perceived best future land use.

4.3. Integration of crowd-sourced data within a technical and socio-political land use regulatory system

There are few historical examples where crowd-sourced participatory mapping data has been used to inform urban and regional zoning plans and thus our observations here are necessarily speculative. Assuming the participatory mapping data is representative and valid, how can it find its way into general land use plans that involve zoning decisions? This outcome will be largely determined by the personal orientation of elected government officials toward the role and value of public participation in land use planning. In the U.S., elected officials have the authority, and are legally responsible, for the adoption of urban and regional land use plans. In their supporting rationale, they can choose to emphasize the physical and technical aspects of land use in their decisions (e.g., the availability of sufficient water to support growth and development), socio-political aspects (e.g., benefits to interest groups such as local businesses), or a combination of the two. In some cases, the physical impacts of land use provide rhetorical cover for what are essentially socio-political value judgments regarding future land use. For elected officials, there are political risks whether or not to embrace participatory mapping to support land use planning decisions. In the absence of broad and representative public participation processes that assess public expectations for land use, officials can maximize their discretionary decision space under the assumption that the public trusts their judgment in zoning decisions. Indeed, empirical evidence suggests that trust in local government is an important predictor of support for zoning (Cooper, Knotts, & Brennan, 2008). However, neglect or tokenism in public participation also bears a downside political risk. Local land use decisions can become a focal point for community conflict and it may be in an official's best interest to anticipate the conflict to keep it socially and politically bounded.

Participatory mapping is not a value neutral planning tool and its historical roots lie in expanding the opportunities to include marginal or non-traditional groups in society to have their interests reflected in important land use decisions. In the Western context, this implies broader public participation beyond traditional interest and stakeholder groups. In Western democracies such as the U.S., there is a propensity toward limited public engagement with land planning processes which can be attributed to a variety of sources (e.g., saliency, trust in government, limited time or knowledge, general decline in civic engagement). This general propensity may be reinforced by local governments where the use of public participation for administrative decision making is limited (Wang, 2001). Local opposition to land use often manifests in project-specific development proposals wherein zoning maps and rules establish the framework for local government response to the proposal. Once zones are established in the general plan, the available options for the public to oppose future land uses that appear consistent with the zone are limited. In most planning systems, the opportunity for greatest public influence in future land use comes not in response to project-specific proposals, but in the development and adoption of the general plan where the community development framework is established. Participatory mapping appears especially well-suited to inform the spatial component of a general land use plan represented by zoning maps.

5. Conclusion

In this study, we described a process by which participatory mapping can be used to assist and inform general land planning and zoning decisions. Future research would benefit from examining whether and how these methods are adopted by local government authorities and to assess their potential impact (or not) in land use decisions. With respect to the participatory mapping methods, an important future research question is the potential effect of NIMBYism ("not in my back yard") in the zoning conflict and compatibility analyses. NIMBYism refers to the propensity for residents living in close proximately to a locally unwanted land use (LULU) to oppose the land use. For example, Pocewicz and Nielsen-Pincus (2013) examined participatory mapping data for evidence for NIMBYism in residential and energy development and found that where people live influenced their preference mapping locations. The NIMBYism effect can be assessed by examining the residential proximity of participants to mapped preferences for opposing land uses, especially those that may be considered a nuisance such as parking or industrial development.

Another important research question is understanding variability in the zoning compatibility scoring based on *who* does the compatibility assessment. Would, for example, Avila Beach community residents reach similar interpretations as local planning officials regarding the consistency of mapped preferences with zoning ordinances? Compatibility judgments between mapped preferences and zoning classifications are inherently subjective and can influence the types of zones that are identified for potential change.

A final consideration for future research would be to relate zoning analysis outcomes to the range of potential zoning changes that participatory mapping data could trigger such as reclassification of the zone, boundary changes, mixed use zones, overlay zones, or the creation of new zoning categories. Can conflict and compatibility index threshold values be more definitely linked to specific types of zoning changes in a general land use plan? More participatory mapping case studies would be needed to establish these threshold guidelines.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2018.04.011.

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