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DETECTION OF LAND COVER CHANGE BY INTEGRATING INFORMATION UNDER LATTICE BASING ON THE COMPLETENESS AND CONSISTENCY

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Abstract. *This paper examines issues in detection of land cover changes. Several causes are identified and treated separately before any relevant "change" decision: (a) errors in signal processing, (b) ontological disagreement on candidate classes, (c) real world updates.*

Basing on these issues, we propose an information quality measure of information before detecting the land cover change. The approach to determine the change is composed the steps: (i) measurement of data quality, (ii) identification of semantic discordances to determine a possible common ontology of land cover classes, which is considered as an information lattice, (iii) integration of information integrating under a lattice based on quality.

Keywords: Land cover change, semantic heterogeneity, completeness, consistency, information lattice, data integration.

1 Introduction

Land cover change detection has become a more common area of research in recent years. It takes as input very large data sources, which can be over entire countries and continents, and compares them, in order to record changes. It has been made possible by the introduction of spatial techniques and of large database facilities. However, direct comparison is problematic because of the large variety of on-the-ground situations containing in a limited number of identified thematic classes, and the user may ignore how the abstraction process was undertaken from raw data to derived thematic products. It is necessary, before integrating these data for time comparison, to identify possible semantic heterogeneity.

This paper proposes a solution to conclude about land cover change by integrating of land cover information under lattice basing on quality information. We consider the Land Cover Map of Great Britain of 1990 (LCMGB) and the UK Land Cover Map 2000 (LCM2k) as case study.

Section 2 describes the land cover change issues as ontological heterogeneity, data quality, and comparison of dominant land cover classes.

Section 3 recalls the information lattice (Phan et al, 2003) which presents the basis for our solution. The notions of complementary and conflicting data are formalized, and the methods for integrating information to identify the consensus and aggregation are given. We propose a methodology to conclude about change, and the results for the case study with LCMGB and LCM2k in the Midlands.

Finally, some concluding remarks and future work are presented in Section 4.

2 Issues of land cover change

Given two thematic maps of an area, with different dates, there are the problem to resolve before conclude about landscape change: semantic heterogeneity, ontology change, quality of information,…

2.1 Ontology heterogeneity

Land cover information, as one of the major sources of geographic information, is highly heterogeneous in formats and semantics. The heterogeneities arise because land cover data are produced basing on different definitions, standards. For example, LCMGB (Fuller et al, 1994) and LCM2k (Fuller et al, 2002, 2003) are produced by the same institution and from composite winter and summer satellite images. LCMGB is raster dataset, recording 25 Target land cover classes; LCM2k is vector dataset, data is provided as polygons of land parcel, and each parcel has a list of attributes attached to it. LCM2K contains different levels of class detail. The standard level of detail provides 26 Broad Habitat land cover classes. LCM2k is not directly comparable with LCMGB because of these heterogeneities.

Solving the problem of ontology heterogeneity, is difficult, is an important task as a preparatory step to the information integration to conclude the landscape change. The aim of ontology integration is building a common ontology or to finding the relation between the concepts of two different ontologies. Several approaches to the integration of heterogeneous ontologies are proposed in Worboys et al (2001, 2002), Foncseca et al (2002) and Stumme et al (2001). Comber et al (2003b) propose a semantic statistical approach for identifying change from ontologically divers land cover data. We aim to build a common ontology of LCMGB and LCM2k. In Pham et al (2003) we have proposed a method to determine the associations between the classes of two ontologies basing on the information in datasets. Further, there are many possible associations between two classes from two different hierarchies (classification systems), some are likely similarities, and some are likely dissimilarities. It is rather difficult to formalize what we mean by similarity and dissimilarity, but when asking an expert, he is in general able to take a decision and to fill up a table such as:

Table 1. Example of an expert look-up table

Classes #2 Classes #1	l_1	l_2	…	l_n
c_1	1	-1		-1
c_2	0	1		-1
…				
c_p	-1	-1		1

This matrix, called a "Look-Up Table" (short: LUT), and precisely an "Expert LUT" can be used to determine a probable transition status between parcels:

For a parcel *A*, suppose that c_i is unique classes of *A* at first date and l_j is unique classes of *A* at second date,

if LUT(i,j) = 1, then *A* is unchanged,
if LUT(i,j) = 0 then status of *A* is unknown,
if LUT(i,j) = -1, then *A* is changed

We combine the result of our approach in Pham et al (2003) and the "Expert LUT" to determine a common ontology of LCMGB and LCM2k on each study zone.

For example, information lattice in Figure 1 represents the result of integration of ontologies. The node containing the classes of different datasets, for instance node 13.1, C1, C2 in Figure 1, where 13.1 is a class of LCM2k and C1, C2 are classes of LCMGB, represents that there is the correspondence between these classes. When we integrate the information of land cover classes (node) in a parcel *A*, if the consensus or aggregation is result in one of these nodes then *A* is unchanged, if the consensus of land cover classes in two dates is its super-class then we can conclude there are mismatches, or internal confusion, or reduced reliability. It depends on the distance between them and their consensus, if the consensus land cover classes in two dates is *bottom* then A is changed. We will clearly present this solution of change detection in Section 3.2.

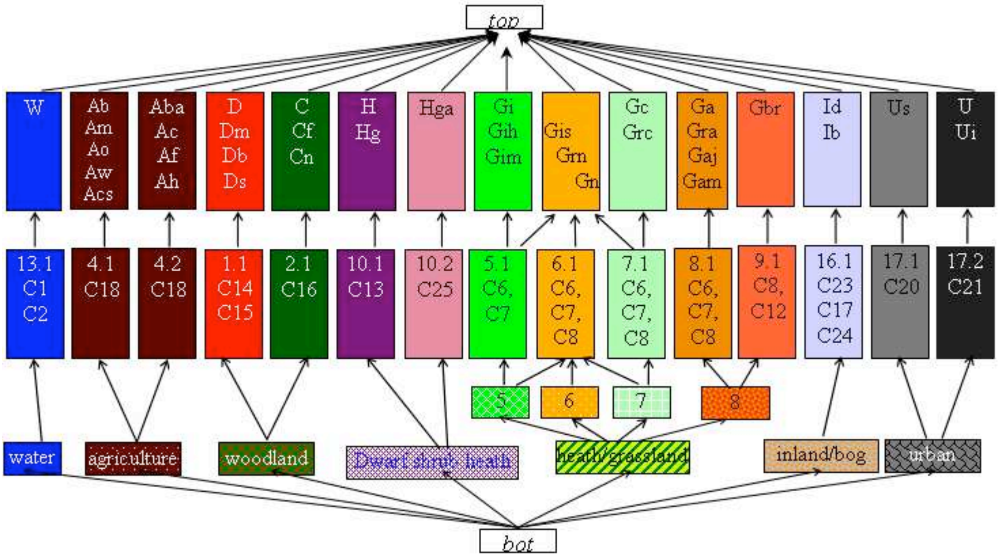


Fig. 1. Information lattice of common ontology of LCMGB and LCM2k

Table 2. the means of abbreviation in Figure 1

W : water
Ab : barley
Am : maize
Ao : oats
Aw : wheat
Acs : cereals
Aba : arable bare ground
Ac : carrots
Af : field beans
Ah : horticulture
D : deciduous
Dm : mixed
Db : open birch
13.1 : water
4.1 : arable cereal
4.2 : arable horticultural
1.1 : broad-leaved wood
2.1 : Coniferous wood
5 : pasture/grassland
6 : semi-natural
7 : neutral and calcareous
8 : acid grass/bracken
C1 : water
C2 : sea/estuary
C6 : mown / grazed turf

Ds : scrub
C : conifers
Cf : felled
Cn : new plantation
H : dense
Hg : gorge
Hga : open
Gi : intensive
Gih : grass
Gim : grazing marsh
Gis : grass setaside
Grn : rough grass
Gn : grass (neutral)
10.1 : dense dwarf shrub
10.2 : open dwarf shrub
5.1 : improved grassland
6.1 : Neutral
7.1 : Calcareous
C7 : pasture/meadow/ amenity grass
C8 : rough / marsh Grass
C12 : bracken
C14 : scrub / orchard
C15 : deciduous woodland
C16 : conifer

Gc : calcareous(managed)
Grc: calcareous(rough)
Ga : acid
Gra : acid (rough)
Gaj : acid with *Juncus*
Gam : acid *Nardus*
Gbr : bracken
Id : despoiled
Ib : semi-natural
Us : suburban/ rural dev.
U : urban residential
Ui : urban industrial

8.1 : acid grass
9.1 : Bracken
16.1 : inland rock
17.1 : suburban
17.2 : continuous urban
C17 : upland bog
C18 : tilled land
C20 : suburban/rural dev.
C21 : urban development
C23 : inland bare ground
C24 : lowland bog
C25 : open shrub heath

3.2 Uncertainty and quality of information in land cover datasets

It may be impossible to represent a true landscape if definitions of soil classes are inherently uncertain or vague. For example, the classes of grass (improved grassland, acid grass, neutral grass,…) is internally heterogeneous. Besides, the lack of information is related to the quantity of information needed for recovering the truth. The lack of information causes the incomplete of dominant subclasses in each parcel. Land cover information consists of basic information describing the land cover classes that occupy the territory, and its assessments via the cartographic representations. When the lack of information of land cover classes exists then the determination of majority class or Broad Habitat (BH) class in each parcel is not exact. For this reason, there exist parcels where the attributed BHs are not the generalization of the dominant subclasses in the complement data (metadata).

For example, the important information (to change detection) is the list of percentage of cover classes (of LCMGB) and the BHs and it metadata (of LCM2k). We note that the information is incomplete (sum of the not null values of percentage is not 100%) then gives rise to the possibility of the inconsistency between BH and it metadata (see an example of data in Table 3).

Table 3. an example of land cover information in LCMGB dataset and LCM2k dataset

LCMGB (1990)				
P#	*PerList*			
1	26% suburban	22% pasture/meadow/ amenity grass	11% tilled land	11% inland bare ground
2	64% inland bare ground	22% tilled land	11% pasture/meadow/ amenity grass	3% suburban
3	37% tilled land	30% neutral and calcareous	4% suburban	2% deciduous woodland
4	…	…	…	

LCM2k (2000)		
P#	*PerPixList (level 1 in information lattice)*	*BH*
1	30%maize, 25%suburban, 11%barley (type a), 11%arable bare ground, 4%barley (type b)	17.1
2	55%carrots, 22%suburban, 7%intensive, 3%field beans	4.2
3	48%grass (neutral), 30%deciduous (type a) , 19%deciduous (type b), 3%mixed	2.1
4	…	

In LCMGB, the observation of land cover classes is imperfect because there exist the parcels which do not contain information of land cover. In LCM2k, the basic information is described by a list (*Parcel#*, *PerPixList*, BH,...) where *PerPixList* is a list of area percentages of the top five spectral subclasses recorded by satellite images within *Parcel#*. The descriptions of BHs (see Figure 1) were developed by the Joint Nature Conservation Committee. LCM2k aimed to contribute to the assessment of habitats by mapping, as far as possible, the widespread examples of terrestrial, freshwater and coastal Broad Habitats (Fuller et al, 2002). We remark that there exist parcels, where the attributed BHs are not the generalization of the dominant subclasses in the parcel. Moreover, the attributed BHs may correspond to non-dominant subclasses.

3.3 A data quality measure

There are many aspects of data quality (Veregin, 1999) as correctness, accuracy, precision, completeness, consistency, relevance and timeliness, etc. In this work, we propose a measure of completeness and consistency of data in LCMGB and LCM2k datasets. We consider:

Completeness of information: The sum of all percentages of non-null values of dominant classes is incomplete. The smaller sum of percentages of dominant classes corresponds to the lower quality.

Consistency: For each *PerPixList*, we regroup the subclasses following the lattice structure. For example, in the first line of Table 2, subclasses maize, barley (type a), barley (type b) are regrouped into class 4.1(arable cereal) with percentage 45, suburban is regrouped into class 17.1 with percentage 25, and arable bare ground is regrouped into class 4.2 (arable horticultural) with percentage 11 (see Figure 1). The result list is sorted in descending order of percentages, called "*TopList*": 2.1, 45: 17.1, 25: 4.2, 11. We say that an estimated broad habitat value is consistent if it is the first value of the *TopList*. Hence, for the first line of Table 2, BH is not consistent with *PerPixList*.

Basing on the above ideas, we propose a method for measure the completeness and consistency of parcel:

Completeness = ∑(*percentage of dominant classes*)

Consistency = *Rang of BH in TopList*

For example, Table 3 represents information after regrouping of information in Table 2 and completeness and consistency in each parcel of its information are presented in Table 4 and Table 5.

Table 4. Completeness and consistency of LCMGB information in Table 3

P#	*TopList*				*Completeness*	*Consistency*
1	26%C20	22%C7	11%C18	11%C23	0.7	*1st*
2	64%C23	22%C18	11%C7	3%C20	1	*1st*
3	37%C18	30%C7	4%C20	2%C15	0.73	*1st*
4	…	…	…			

Table 5. Completeness and consistency of LCM2k information in Table 3

P#	*TopList*			*BH*	*Completeness*	*Consistency*
1	45%2.1	25%17.1	11%4.2	17.1	0.81	*2nd*
2	58%4.2	22%17.1	7%5.1	4.2	0.87	*1st*
3	52%1.1	48%2.1		2.1	1	*2nd*
4	…	…	…			

4 Land cover change

4.1 Existing methods

The problem of detecting change between thematic (land cover) maps is described by Fuller et al (2003) with reference to the accuracy of LCMGB and LCM2k. With the assumptions of random error distribution, ignoring different types of thematic errors and change, they show the underlying problems of change detection that exist with respect to map accuracies stating that to detect a change of 17% (the likely rate of change cited by Fuller, 2003) with a 75% reliability both maps would have to be 97% accurate. In reality LCMGB and LCM2k are between 70% and 80% accurate.

Statistical approaches are based on commutating surface percentages for each class, at each date, then compiling "transition matrices" (Eiden et al 2003, Comber et al 2003c), and finally defining a threshold which splits between what should be interpreted as a "change" or not.

Most improvements proposed for theses approaches concern the way the "surfaces" are computed, paying attention to the "internal data quality", not to the external quality. At the European scale, a lot of studies have been done for the CORINE Land-Cover program (see (IES)), whose LCMGB is the British subset. The overall results are used as very broad indicators only, and in general they are reputed "overestimated".

Fuller et al (2003) indicate that a possible way forward for detecting land cover change between, is to utilize the vector structure of LCM2k to interrogate the LCMGB raster data. This provides local descriptions of LCMGB distributions, and allows change to be identified on a per-parcel basis. A complementary description of LCM2k parcel heterogeneity is provided by one of the LCM2k meta-data attribute *PerPixList*. Comber et al (2003a; 2003b; 2003c) have developed and applied a methodology that compares two parcel characterizations based on *PerPixList* attribution and the distribution of LCMGB classes, in order to identify locales of change.

4.2 Data quality based integration under lattice to detect the land cover change

4.2.1 Information lattice

An *information lattice* is a lattice (L, $\leq$), which contains *top* (inconsistent) and *bottom* (unknown). $\leq$ is partial order between the elements of L, *top* is maximal element and *bottom* is minimal element of L. Let x, y in L, if $x \leq y$ then y is called more *complete* or more *specific* than x. In the case L is a lattice of land cover classes if $x \leq y$ then y is subclasses of x. Let $X \subseteq$ L such that $X \neq \varnothing$, the set of all minimal (resp. maximal) elements of X is denoted by $min(X)$ (resp. $max(X)$). The least upper bound of X, if exists, is denoted by $\vee X$, and called the *join* of X. The greatest lower bound of X, if exists, is denoted by $\wedge$X, and called the *meet* of X. In particular, if $X = \{x, y\}$ then $\vee X$ and $\wedge$X, respectively denoted by $(x \vee y)$ and $(x \wedge y)$, always exist. We have $(x \wedge y) \leq x, y \leq (x \vee y)$, and the following equivalence: $x \leq y$ if and only if $x = (x \wedge y), y = (x \vee y)$.

If $(x \vee y) \neq top$, then x and y are called *complementary* to one another. If $(x \vee y) = top$, then x and y are called in *conflict* with each other. The conflict between x and y is called total if $x \wedge$ y = *bottom*, as x and y do not share any common information. Otherwise, the conflict is called partial, and $x \wedge y$ is called a *consensus* of x and y.

Let I and J be subsets of L. We define $I \sqsubseteq J$ if $I = \varnothing$, or for each $x \in I$, there exists y in J such that $x \leq y$. J contains the information of I. I is called an *information containment* of J.

Let I and J be subsets of L, I is called a *information equivalence* of J if and only if I is an information containment of J, and J is an information containment of I.

Let (L, $\leq$) be an information lattice. Let I and J be subsets of L. If I and J are non-empty, then define the *consensus* and the *aggregation* of I and J to be respectively

$\otimes$: $I \otimes J = max\{ x \wedge \mathrm{y} \mid x \in I, y \in J \}$

$\oplus$: If $I \sqsubseteq J$ (or $J \sqsubseteq I$) then $I \oplus J = max(J)$ (resp. $max(I)$), else $I \oplus J = max\{ x \vee \mathrm{y} \mid x \in I, y \in J \}$

Example: Figure 1 represents an information lattice of land cover classes, 4.1 ≤ *Ab* or *barley* is subclass of *arable cereal*: 4.1 ≤ *Am* or *maize* is subclass of *arable cereal*. The consensus of 1.1 (*broad-leaved wood*) and C16 (*conifer*) is *woodland*. 13.1 (*water*) is total conflict with 17.1 (*suburban*). 8.1 (*acid grass*) is partial conflict with C8 (*rough / marsh Grass*). 5.1 (*improved grassland*) is a complement of 6.1 (*neutral*). There exists internal confusion between 5.1 (*improved grassland*) and 6.1 (*neutral*). It is called internal heterogeneity.

4.2.2 Data preparation

The necessary information to our methodology is:

- the information lattice which represents the common ontology of land cover classes,
- the quality information is available in each datasets,
- the "*toplist*" (list of regrouping the subclasses into level of Broad Habitat, remark that this list is sorted in descending order of percentages).

It means that each parcel *A* is described by triplet (*A* | *toplist* | *completeness*, *consistency*) in LCMGB and LCM2k, where *A* is the code of parcel, *toplist* is information of land cover classes. The lattice information will be used for integration process.

4.2.3 Integration for determination of consensus

Suppose parcel *A* is covered by only one class C_i of LCMGB and class L_j of LCM2k. In section 1, the consensus of C_i and L_j is $C_i \otimes L_j = C_i \wedge L_j = x$. When x is in a same node of C_i and L_j, *A* is unchanged. If C_i and L_j is subclasses of x then we can conclude there are the mismatch in *A*. In this case, the level of change-nochange depends on the "distance" between x and C_i, L_j. If the x is *bottom* then we can say that *A* is changed. The level of change is as following:

$C_i \longleftrightarrow L_j$: $\neg p$ (no change)
$C_i \dashleftarrow\dashrightarrow L_j$: $\neg p'$ (no change with warning)
$C_i \dashleftarrow\cdots\dashrightarrow L_j$: p' (indecision)
…
$C_i \cdots\cdots L_j$: p (change)

When the parcel *A* is covered by many classes $\{C_i\}$ of LCMGB at first date, and many classes $\{L_j\}$ of LCM2k at second date. The change measure is calculated basing on the consensus of pair-wise of classes from two sources. This measure is represented in next section.

4.2.4 Query with the user's constraints on quality

The users can specify a quality level when querying the integration of land cover information to detecting the change. When the constraints on quality of user's queries are introduced, the integration process will choose the information, which satisfies the needs of user, for fusion. The constraint on quality is intended to limit the computation to parcels which present enough information for making a decision of change.

With the constraint on quality is *completeness* $\geq c_1$ and *consistency* = $\{I\}$. For each parcel *A*,

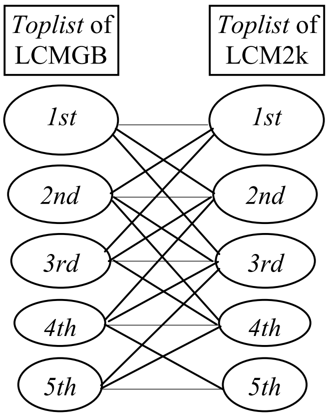
If $com_1(A) \geq c_1$ and $com_2(A) \geq c_1$ and $con_1(A) \in \{I\}$and $con_2(A) \in \{I\}$ then

the change/nochange conclusion is realized by *integration process for detecting of change.*

Else the parcel is colored by white (lack information for change conclusion).

The *integration process for detecting of change* in the parcel:

1st step: fusion *toplist* of LCMGB and *toplist* of LCM2K. It integrates a pair-wise of *toplist* to calculate the consensus of land cover classes.



f_{11} = (1^{st} of LCMGB ⊗ 1^{st} of LCM2k)
f_{12} = (1^{st} of LCMGB ⊗ 2^{nd} of LCM2k)
f_{13} = (1^{st} of LCMGB ⊗ 3^{rd} of LCM2k)
f_{21} = (2^{nd} of LCMGB ⊗ 1^{st} of LCM2k)
f_{22} = (2^{nd} of LCMGB ⊗ 2^{nd} of LCM2k)
f_{23} = (2^{nd} of LCMGB ⊗ 3^{rd} of LCM2k)
f_{24} = (2^{nd} of LCMGB ⊗ 4^{th} of LCM2k)
…

<u>2</u>

2nd step: build the preference order to conclude about change

In each *toplist*, the classes in descending order play the different part to detecting the "change". The major class plays the important part of "change". In order to present this, the classes of *toplist* are coded by binary code which is "degree of importance", each *toplist* = (1^{st} class, 2^{nd} class, …, n^{th} class) is coded by (2^{n-1}, 2^{n-2}, … ,2^0), with n is maximal number of element in *toplist* of all parcels. We note that if a *toplist* have k elements, $k < n$, then element $k+1$, $k+2$, …n is null classes. It means that and *coef*(1^{st} class) = 2^{n-1}, … *coef*(2^{nd} class) = 2^{n-2}…

The coefficient is assigned to each element (i,j) of this matrix:

$$coef(i,j) = coef(i) * coef(j)$$

For example, with the *toplist* = (1^{st} class, 2^{nd} class, 3^{rd} class), the result of two *toplist* integration from two sources is:

$$\begin{array}{ccc} f_{11} & f_{12} & f_{13} \\ f_{21} & f_{22} & f_{23} \\ f_{31} & f_{32} & f_{33} \end{array}$$

The "degree of importance" of the integration result of two *toplist*:

$$\begin{array}{lll} coef(1,1) = 16 & coef(1,2) = 8 & coef(1,3) = 4 \\ coef(2,1) = 8 & coef(2,2) = 4 & coef(2,3) = 2 \\ coef(3,1) = 4 & coef(3,2) = 2 & coef(3,3) = 1 \end{array}$$

We call d(f_{ij}) is short way from f_{ij} to *bottom* or the "near" of f_{ij} and "change". By definition, if f_{ij} = *bottom* then d(f_{ij}) = 0, elseif "distance" from f_{ij} to *bottom* is k then d(f_{ij})=2^k.

The "quantitive nochange" is defined by

$$\sum_{ij} (coef(i,j) * d(f_{ij}))$$

When the "quantitive nochange" is greater then the possible change is smaller.

3rd step: change decision basing on the preference order.

As an example to conclude the change: with the *toplist* = (1^{st} class, 2^{nd} class, 3^{rd} class), d(f_{ij}) ∈{0, 2, 4, 8} (d(f_{ij}) = 0 if f_{ij} = *bottom*, d(f_{ij}) = 2 if f_{ij} is a successor of *bottom*, …). If the "nochange" is concluded if the major classes of two *toplist* are a same node in information lattice, then the thresholds for change decision are:

Nochange if $\sum_{ij} (coef(i,j) * d(f_{ij})) >= 512$

Indecision if $\sum_{ij} (coef(i,j) * d(f_{ij})) >= 256$

Change if $\sum_{ij} (coef(i,j) * d(f_{ij})) < 256$

4.3 Results

Figure 3 and Figure 4 display the same midland zone: Figure 3 shows the map of majority class taken from LCMGB; Figure 4 is the map of Broad Habitat of LCM2k, colored according to the LCM2k display class description. The parcels color white lack information of land cover classes.

Figure 5 displays the change when the integration takes as input the major class of LCMGB and Broad Habitat of LCM2k. The constraint on quality for query of integration is (completeness >=50%) and (consistence = *first*). This constraint is "strong", for this reason there many parcels detected change. There are 40.22% nochange, 2.09% indecision, 38.23% change, 19.46% white.

[legend: no change= *green*, change= *red*, indecision= *yellow*, *white*= insufficient information for decision]

Figure 6 displays the result of integration query, which takes as input the "*toplist*" of LCMGB and "*toplist*" of LCM2k. The constraint on quality for query of integration is (completeness ≥ 50%) and (consistence = {*first*, *second*, *third*}). There are 40.22% nochange, 22.52% nochange with warning, 16.08 indecision, 1.72% change, 19.46% white.

[legend: no change= *green*, indecision= *yellow*, indecision "near change" = *orange*, change = *red, white*= insufficient information for decision]

5 Conclusion and future works

We have presented a solution to conclude about of land cover change. This solution takes into account constraints on quality information related to the completeness and consistency degree of classification of each parcel and to internal conceptual consistency. Then it integrates the two land cover class hierarchies under a common information lattice and proposes a way to identify the consensus of land cover classes at two dates. This consensus is relevant for determining the mismatch of land cover classes, and is used to conclude about the level of land cover classes, and is used to conclude about the level of change. The constraint on quality is intended to limit the computation to parcels which present enough information for making a decision of change. Experimental results have been performed on real-scale data and show some interesting properties, reducing the overestimation of change which is frequently computed with classical statistical methods.

We have proposed a common ontology for LCMGB and LCM2k on a zone study. This ontology is determined combining the expert opinion and the real information in the datasets. Consequently the common ontology of a zone is not suitable another zone or the all case. So it is necessary to thoroughly examine the ontology heterogeneity.

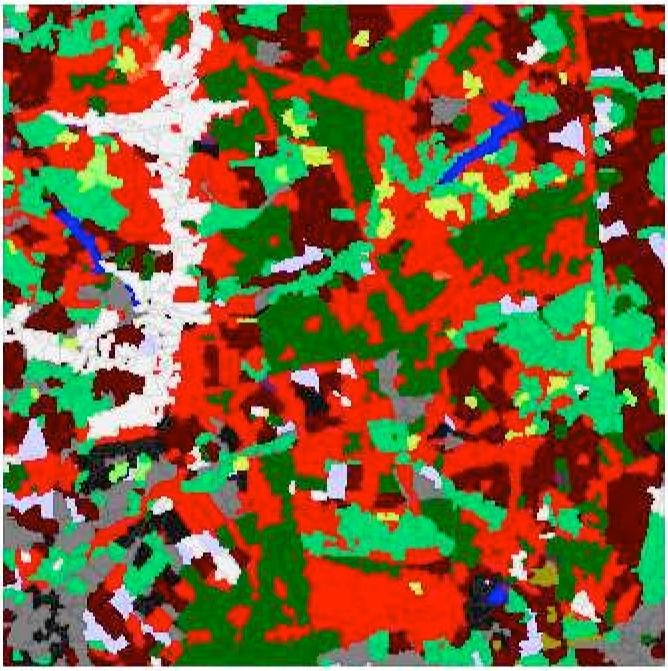


Fig 3. *LCMGB map display of majority class*

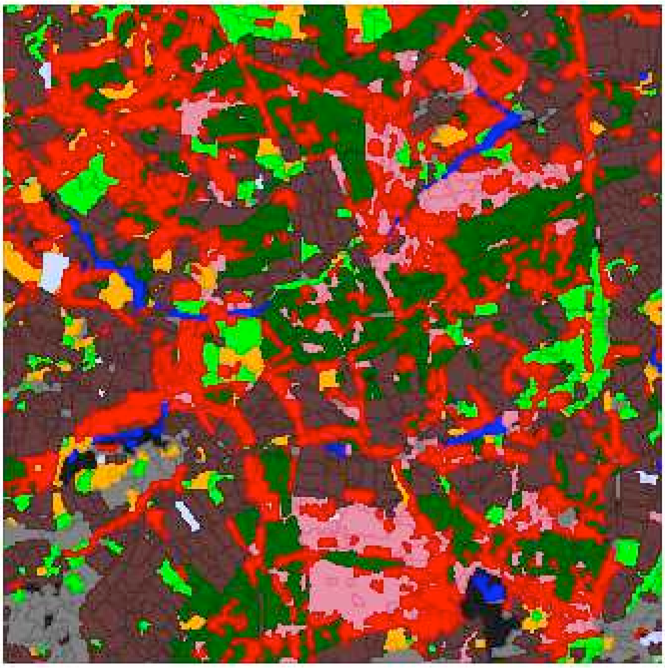


Fig 4. *Broad Habitat display of LCM2k*

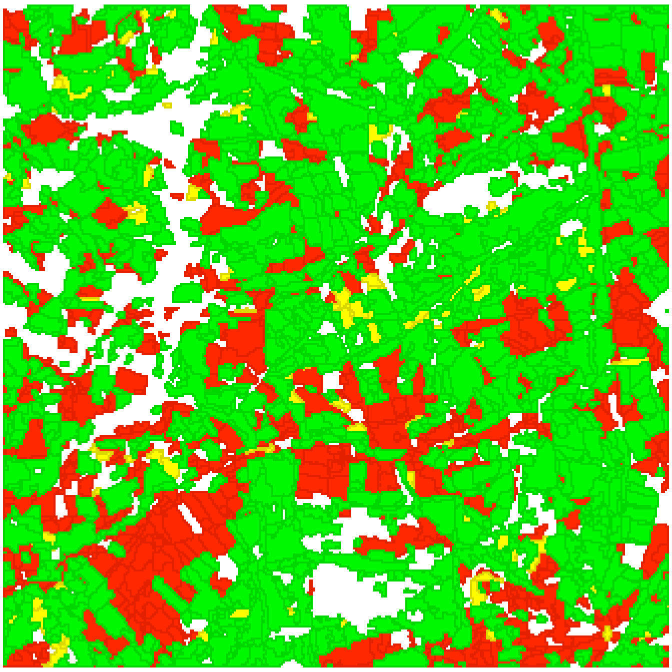


Fig. 5. *majority class change completeness ≥0.5 and consistency = {first}*

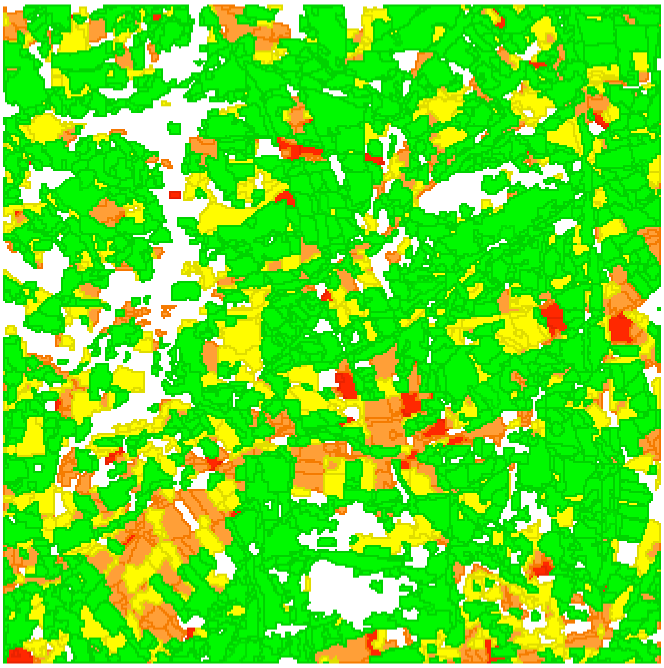


Fig. 6. *change with completeness ≥0.5 and consistency = {first, second, third}*

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