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Simulations of effects of development and climate change scenarios on hydro-ecology of the Okavango Delta

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Water and Ecosystem Resources for Regional Development

WERRD

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Introduction

This work relates changes in hydrological inputs, simulated for various possible upstream development and climate change scenarios, to changes in extent, frequency and duration of flooding in the Okavango Delta. It must be emphasised that this assessment deals only with effects related to change in temporal distribution and magnitude of water inputs. The effects of changes such as change in amount of sediment resulting from the considered scenarios are not assessed. Also, changes in the structure of the hydrological system of the Okavango Delta (i.e. permanent flow shifts) are not taken into account. These are potentially much stronger instruments of hydrological change.

Methods

The results of simulation of hydrological change in the Okavango Delta due to future development and climate change are to be used, in the framework of the WERRD project, to assess impact on Delta ecosystem. The hydrological change is, therefore, presented here by means of variables that can be directly linked to ecosystem processes through relating them to functional floodplain classes. SMEC (1989) distinguished four classes of floodplain based on frequency of flooding with minor subdivisions based on duration. This was the first classification to recognise the occurrence of different communities in areas with different flooding characteristics in the Delta, and in the absence of other classification systems, we have used its modified version in this study (Table 1).

The assessment of effects of possible future changes in hydrological inputs on the hydrological characteristics of the Okavango Delta was done using the hydrological model of the Okavango Delta described in D2.3. It was done by modifying the past time series of inputs to reflect possible future changes, and comparing the simulated hydrological characteristics with those of the unmodified time series. The assumption underlying the adopted approach was that we were interested in obtaining indices of change in relation to past and contemporary conditions, rather than to explicitly simulate future conditions. Such an approach was possible since the characteristics of the hydrology of the system are not defined as pertaining to a single flood, but rather to conditions prevailing over several years (average), and these are reflected well in the past time series. In this setting, comparison of various scenarios is relatively straightforward.

The suite of scenarios run is presented in Table 2 and 3. For details of the scenarios, the reader is referred to materials prepared within WP1.

The available observed time series of hydrological inputs to the Delta, both inflow and local rainfall, is non-stationary. This non-stationarity is caused by the presence of sequences of wetter and drier years, and is often described as a quasi 80-year cycle (Wolski et al., 2002; McCarthy et al., 2000), the persistence of which over the last 3000 years has been indicated by palaeoclimatic data (Tyson et al., 2002). That cyclicity has not yet been resolved by global/regional climate models, and a discussion of the veracity and driving forces of the cyclicity is beyond the scope of this report. The Delta has been subject to three general wetness regimes in the recent past called here: wet (1974-1985), transitional (1985-1990) and dry (1990-2000). The wet and dry periods were of sufficient duration and consistency to result in the establishment of a particular distribution of wetland herbaceous cover and, to a lesser extent, woody cover. Irrespective of the cause of these regimes, neither can be considered a reference “normal” situation (both are normal, yet different). If the assumption of the climatic cyclicity is true, both are likely to repeat themselves in the future. Given this situation, our assessment of future change was undertaken separately for wet and for dry conditions.

Assessment of the effects of simulated future changes comprised several steps_including (1) determining change in hydrological inputs to the Delta, (2) modelling of flood extent by means of hydrological model of the Okavango Delta, (3) deriving flood characteristics at the spatial resolution of the GIS model (4) determining extent and size of functional flood class units (5) determining change in size and distribution of functional ecological units under various development and climate change scenarios

Step 1 - Determining change in hydrological inputs to the Delta

For climate change, the future change in hydrological inputs was imposed on the observed past time series using the concept of change factor in a variable *Var*, i.e. $\Delta(Var)$, where:

$$Var_{average,\mathrm{future}} = \Delta(Var)\cdot Var_{average,\mathrm{past}}$$

The values of $\Delta(Var)$ were derived from climate models (described in WP1) for rainfall, air temperature and humidity. These were applied to modify the observed time series of local rainfall and variables used for calculating local potential evaporation for each time step:

$$Var_{\mathrm{scenario}} = \Delta(Var)\cdot Var_{\mathrm{past}}$$

Implementation of $\Delta(Var)$ for the Okavango catchment was done in the catchment model as described in WP1. The output of the catchment model for each of the scenarios was then taken as the input to the Delta.

Several scenarios of future climate were considered here (Table 2). These scenarios were simulated by three global climate models (CCC, HadCM3 and GFDL) for different scenarios of greenhouse gases emissions (A2 and B2). For detailed description of the models and methods used see deliverables of WP1. For development scenarios (Table 3), the modified inflow time series, obtained from Okavango catchment model developed in WP1, was applied. These are all upstream in the catchment as no developments in the Delta proper were simulated.

Step 2 – Modelling flood extent under scenarios by means of hydrological model of the Okavango Delta

The hydrological model used is described in detail in D2.3. The model simulates flooding in the Delta using a linear reservoir concept. Hydrological inputs are routed through a set of interlinked reservoirs representing major distributaries in the Delta, and a value of flood extent as well as fluxes in and out of a reservoir are obtained for each distributary at a monthly time step. The lumped value of flood extent is then used as an input to a GIS model in which the spatial distribution of that flood is determined based on a 15 year time series of flood maps. Although the spatial resolution of the hydrological model is very coarse (units vary in size from 500-2 000 km^2), the GIS model provides the distribution of flood at a much finer spatial resolution, 1 by 1 km.

Flood maps show some variation in flood distribution for floods of similar size from different periods. The available data do not permit distinction between possible causes of this variation, such as misclassification and mis-registration of satellite images used to derive flood maps and natural variation in flood extent. Therefore flooding at the 1 by 1 km pixel size was described in a probabilistic manner: for each of the pixels, the probability of being flooded by a flood of size x was described by a probability distribution function F(x) corresponding to the normal distribution. Parameters of F(x) were derived for each of the pixels based on the analysis of the flood map series.

Although the GIS model allows for performing analyses in a probabilistic manner (i.e. deriving a suite of flood characteristics for a pixel together with their associated probabilities) for the sake of simplicity we decided to work with the most probable situation only.

Step 3 - Deriving flood characteristics at the spatial resolution of the GIS model

The flood characteristics of concern are flooding frequency and flood duration. These were derived by analysing the stacked flood maps of the most probable flood distribution for each of the months in the modelled time series of flood sizes.

Step 4 - Determining extent and size of functional flood class units

Each of the major functional flood class units as shown in Table 1 is characterized by a specific combination of flooding frequency and duration of inundation. By classifying flood characteristic maps obtained in step 3, it was thus possible to obtain maps showing the distribution of the functional flood plain types, hereafter referred to as floodplain classes.

Step 5 - Determining change in size and distribution of functional ecological units under various development and climate change scenarios

Steps 2, 3 and 4 were performed on the time series of flood sizes simulated by the model for the past (baseline) conditions, for which observations were available and for which the model was calibrated. To obtain flooding characteristics under changed inputs, steps 2, 3 and 4 were repeated for the past time series modified to reflect anticipated future change. The extent of change was assessed by calculating the areas for which change in floodplain class occurred between given scenario and the baseline simulation.

Results

Development scenarios

Development scenarios can be divided into 4 qualitatively different types: abstraction (scenarios D2, D4, D8, D10 and D12), deforestation (scenarios D5 and D11), damming (D3 and D9) and combined (D6, D7, D13 and D14). Results of development scenario simulations are presented in Fig. 1, Fig. 2, Fig. 6 and Fig. 7.

The effect of abstractions is to reduce inflows both during the low flow as well as during the high flow periods. As a result, there is a reduction in the size of the permanently inundated area, and increase in the size of dryland. The total size of the seasonal and occasional floodplains remains approximately the same, but the zone occupied by them “retreats” towards centre of the Delta.

The effect of deforestation is to increase inflows throughout the year, with stronger effect seen during peak flood. As a result, there is an increase in size of all the functional units but the dryland. That increase is strongest for the permanent floodplains, while for seasonal floodplains it is lower. The zones occupied by each of the units, obviously, shift towards the peripheral parts of the Delta.

The effect of damming is to reduce peak flows and increase low flows. However, due to the way the dams operate, these are strongly visible during wet years, and during transition from wet to dry years, but less during dry years. During wet years the effects of damming cause increase in the size of permanent floodplains and reduction in the size of seasonally inundated floodplains. The size of dryland increases.

The combination scenarios account for all of the above factors. Since the “pure” scenarios induce sometimes effects opposite to each other (e.g. deforestation cause increase, while abstractions cause decrease in inflows to the Delta), there is no clear direction of change in case of combination scenarios, and the effects vary between dry and wet years. For the scenarios combining deforestation and abstractions, there is a reduction in permanent floodplain area during dry years and no change or increase during wet years. There is a consistent increase in the area of seasonal floodplains. When all three factors are introduced simultaneously, the effects of dams largely cancels the effects of deforestation causing more regular flooding with virtual cessation of the effects of high floods (<0.1 frequency).

The effects simulated by the development scenarios are in general small compared to these caused by the natural variation in flows and local rainfall as presented in Fig. 5.

Climate change scenarios

Results of development scenario simulations are presented in Fig. 3, Fig. 4, Fig. 8 and Fig. 9.

Global climate models predict future conditions in the Okavango basin ranging from drier than present to wetter than present, and there are differences in both degree of change and direction of change between the Okavnago river catchment area and the Okavango Delta proper. The subtle interplay of change in the catchment and change in Delta proper as obtained from GCMs produces a wide spectrum of possible future conditions in the Delta. It is beyond the scope of this work to assess which of the used climate models and scenarios for greenhouse gases concentrations is the most realistic one. Important here is that there is a large uncertainty about the future climatic conditions. Also, the effects of climatic variation on the hydrology of the Delta are very strong – much stronger than these of development.

Climate conditions simulated by the HadCM3 model result in consistent, progressive and strong drying of the Delta. CCC and GFDL, however, simulate wetter conditions during the 2020-2050 period. For later periods (2050-2080 and 2070-2090), simulated conditions vary from wetter to drier, depending on the model and greenhouse gas scenario.

Tables

Table 1 Hydrological characteristics of major functional floodplain classes in the Okavango Delta. Modified after SMEC (1989).

Floodplain class	Sub-class	Class code	Flood frequency	flood duration (months/year)
Permanent floodplain	proper	PF1	1	12
	fringe	PF2	1	8-12
Regularly flooded seasonal floodplain		RF1	1	4 – 8
		RF2	0.5-1	
Occasionally flooded seasonal		OF	0.1-0.5	1-4
High floods only		HFO	<0.1	<2
Dryland		DL	0	0

Table 2 List of simulated development scenarios

Scenario number_type	impact type	prognosed for year
D1_ref	Reference conditions	
D2_abs	water use (domestic, livestock, tourism):	2015
D3_dam	Dams	
D4_abs	Irrigation	
D5_def	deforestation 1 km from rivers	
D6_com	irrigation and water use + deforestation 1 km from rivers (no dams)	
D7_com	dams, irrigation and water use + deforestation 1 km from rivers	
D8_abs	water use (domestic, livestock, tourism):	2025
D9_dam	all potential dams	
D10_abs	irrigation (5% of potential land around Menongue and Cuito-Cuanavale and at least 15% of potential irrigable land downstream)	
D11_def	deforestation 2 km from rivers	
D12_abs	pipeline to Windhoek	
D13_com	irrigation + water use + deforestation 2 km from rivers + pipeline (no dams)	
D14_com	dams + irrigation + water use + deforestation 2 km from rivers + pipeline	

Table 3 List of simulated climate change scenarios

Scenario number	Climate model	Greenhouse gases scenario	Prognosed for years
2	HadCM3	A2	2020-50
3	CCC		
4	GFDL		
6	HadCM3	B2	
7	CCC		
8	GFDL		
10	HadCM3	A2	2050-80
11	CCC		
12	GFDL		
14	HadCM3	B2	
15	CCC		
16	GFDL		
18	HadCM3	A2	2070-2090
19	CCC		
20	GFDL		
22	HadCM3	B2	
23	CCC		
24	GFDL		

Figures

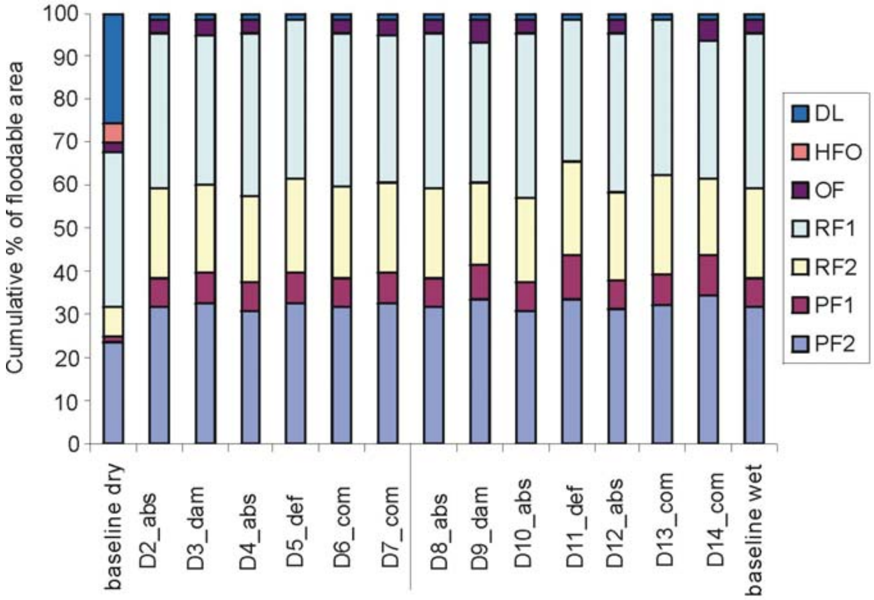


Fig. 1 Percentage of floodable area covered by various floodplain classes under various development scenarios, wet conditions

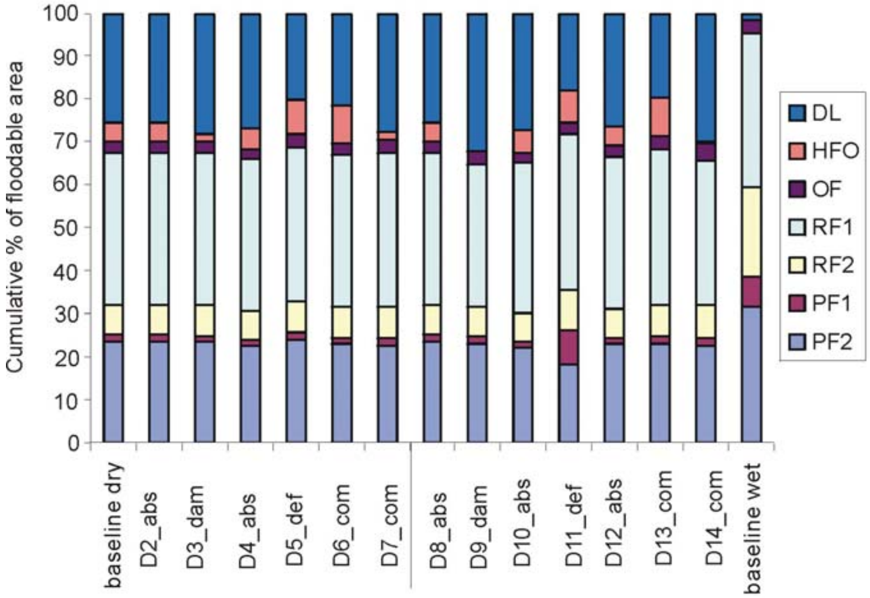


Fig. 2 Percentage of floodable area covered by various floodplain classes under various development scenarios, dry conditions

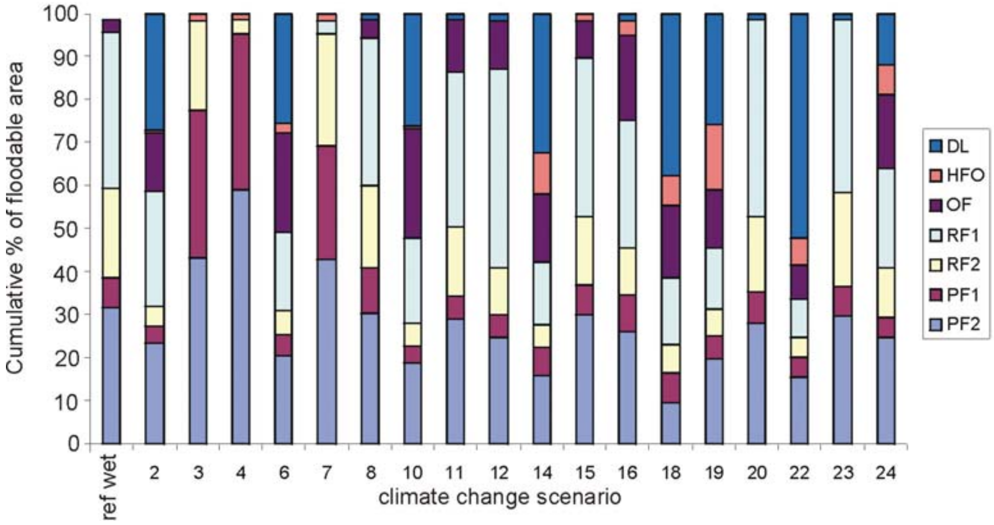


Fig. 3 Percentage of floodable area covered by various floodplain classes under various climate change scenarios, wet conditions

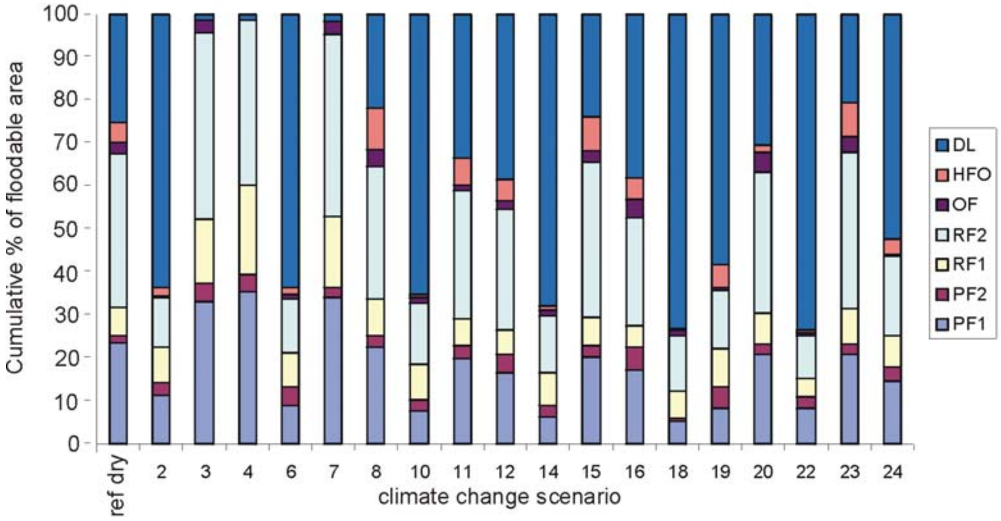


Fig. 4 Percentage of floodable area covered by various floodplain classes under various climate change scenarios, dry conditions

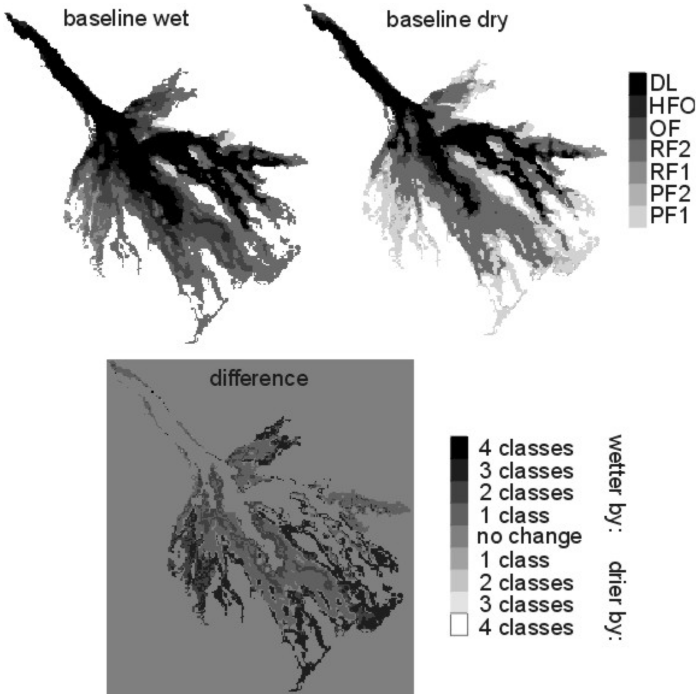


Fig. 5 Distribution of floodplain classes for wet and dry baseline conditions, and difference in class between these conditions

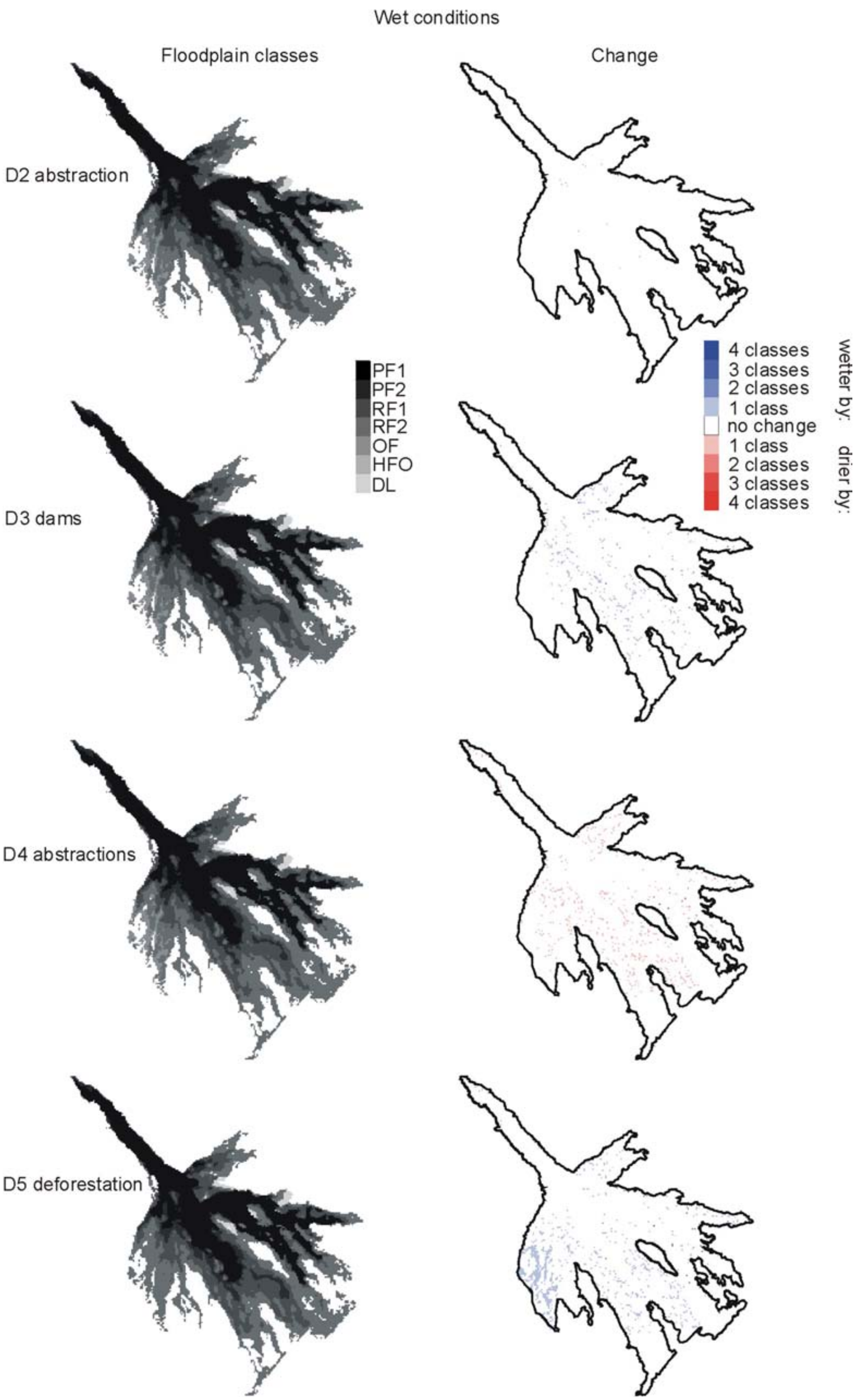


Fig. 6 Distribution of floodplain classes and difference in class with respect to baseline conditions, development scenarios, wet conditions

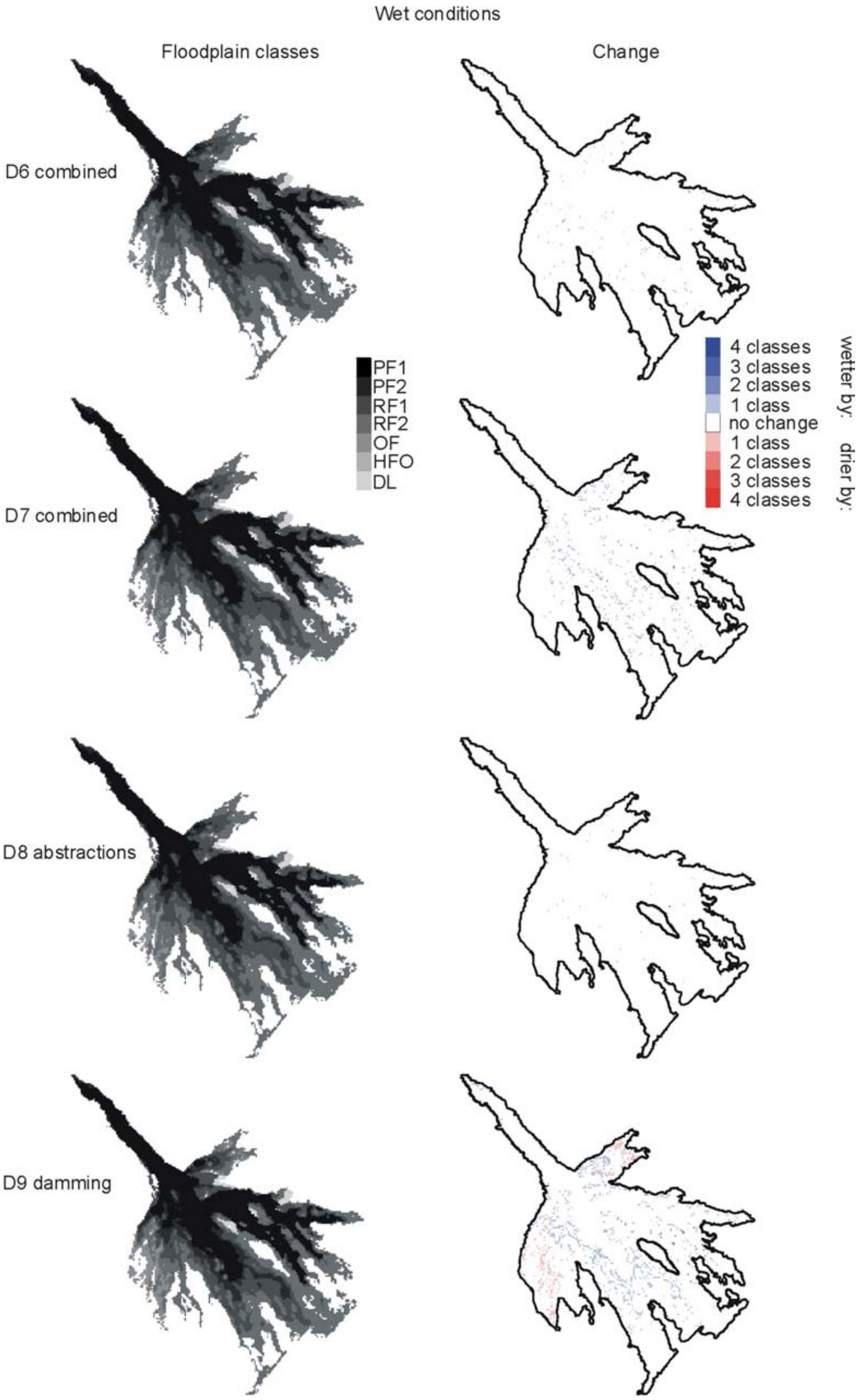
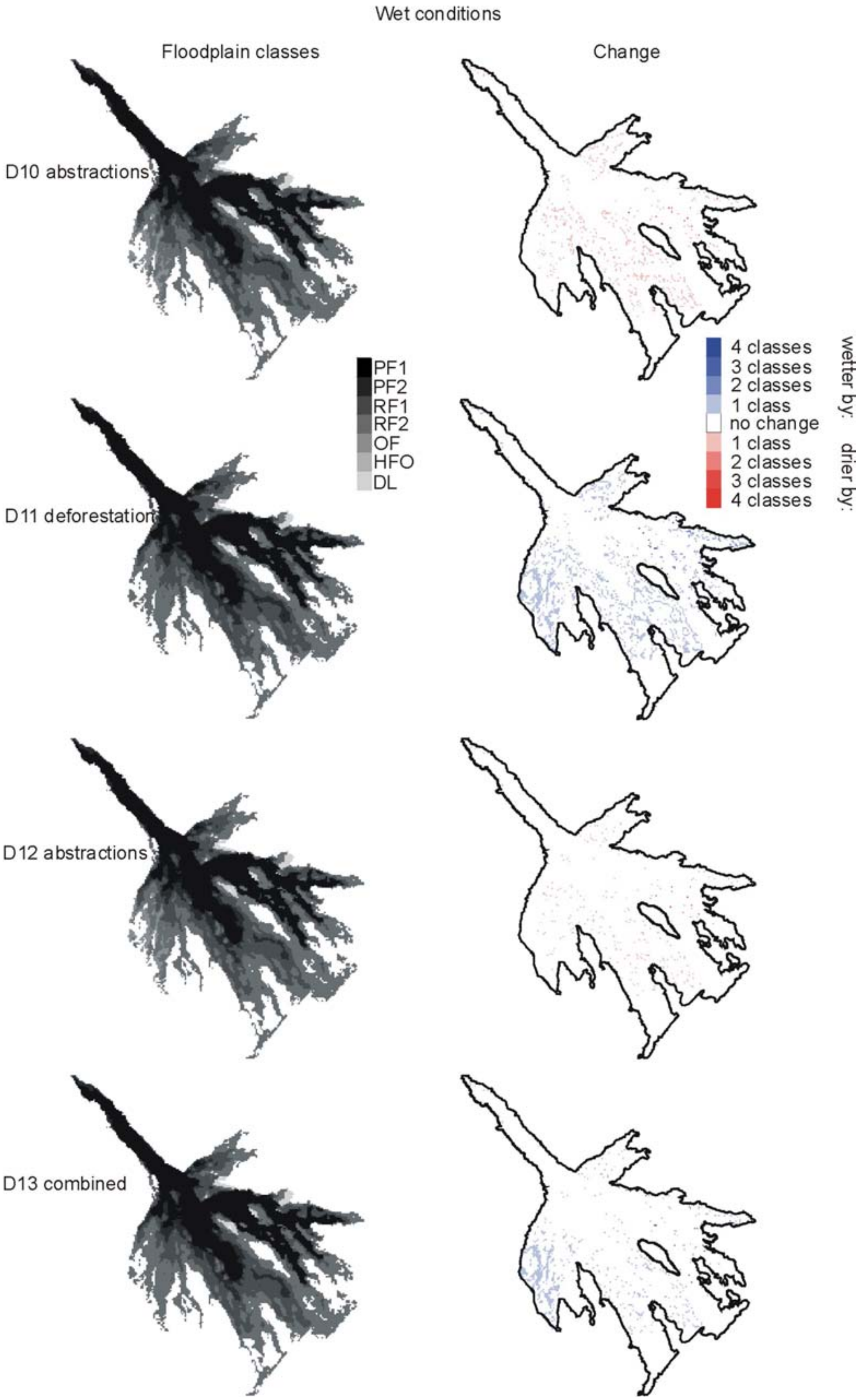

Wet conditions
Floodplain classes
Change
D6 combined
D7 combined
D8 abstractions
D9 damming
PF1
PF2
RF1
RF2
OF
HFO
DL
wetter by:
4 classes
3 classes
2 classes
1 class
no change
drier by:
1 class
2 classes
3 classes
4 classes

Fig. 6 cont.


Wet conditions
Floodplain classes
Change
D10 abstractions
D11 deforestation
D12 abstractions
D13 combined
PF1
PF2
RF1
RF2
OF
HFO
DL
wetter by:
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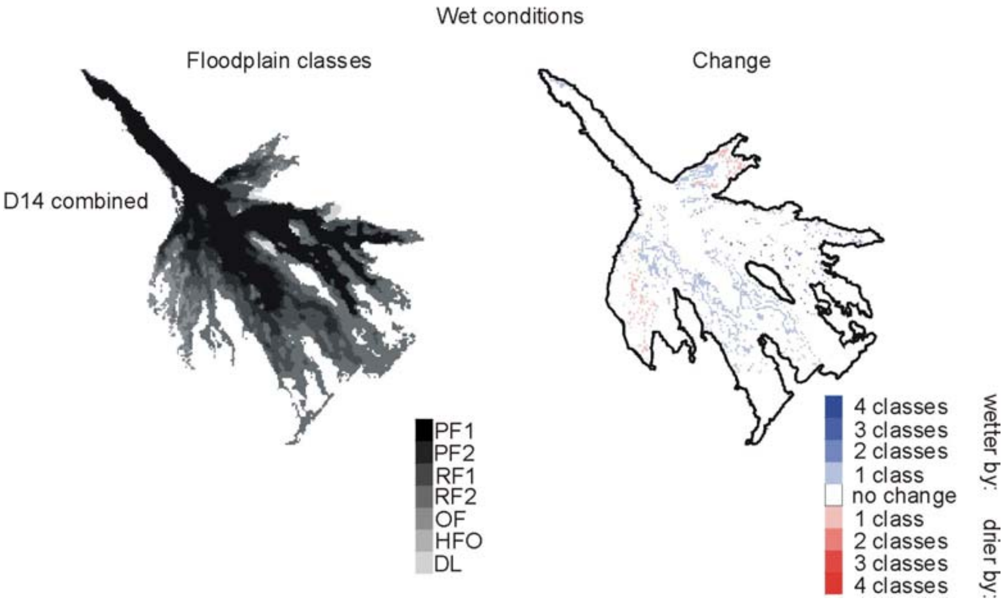
3 classes
2 classes
1 class
no change
drier by:
1 class
2 classes
3 classes
4 classes

Fig. 6 cont.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D14 combined
PF1
PF2
RF1
RF2
OF
HFO
DL
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no change
1 class
2 classes
3 classes
4 classes
wetter by:
drier by:

Fig. 6 cont.

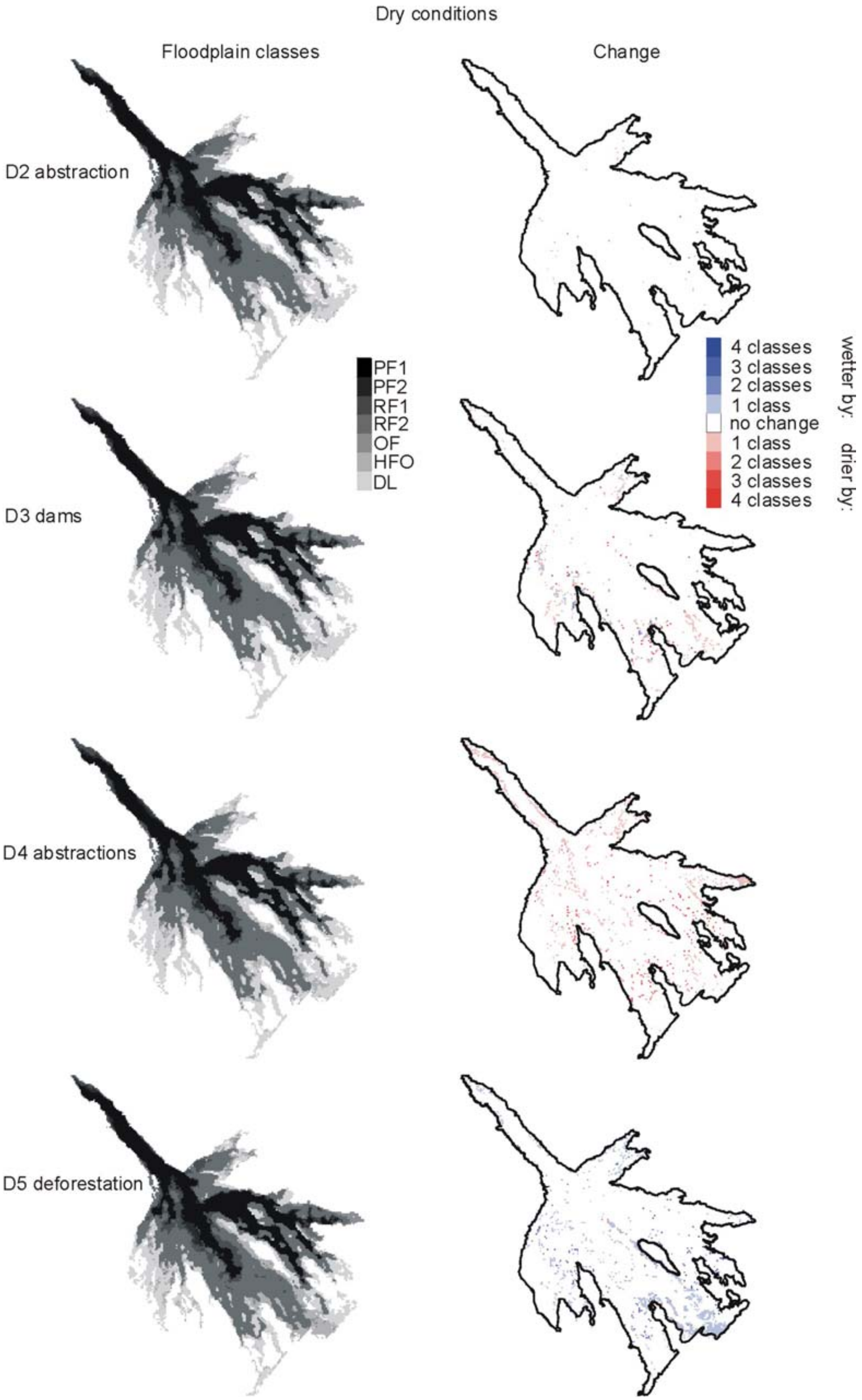
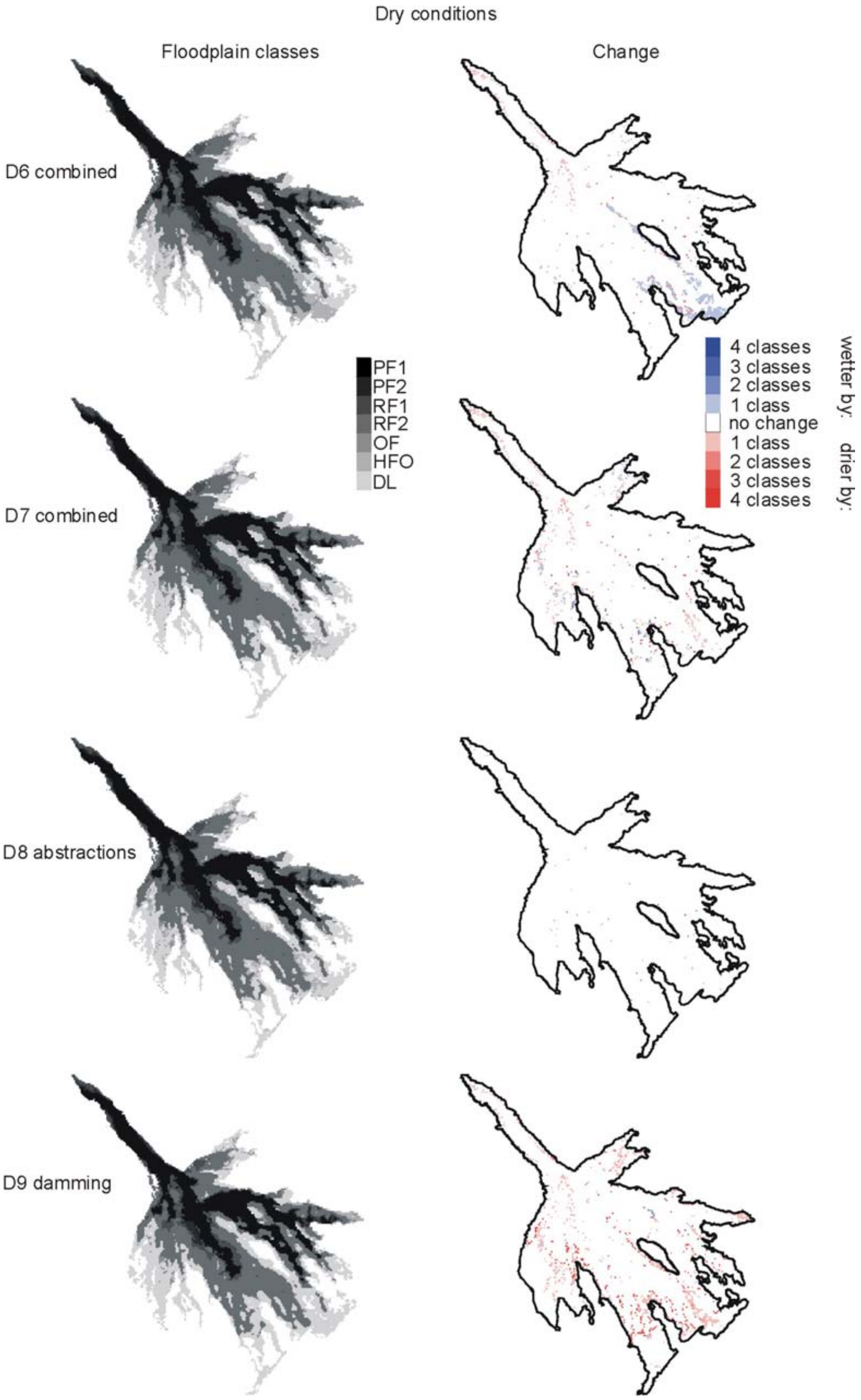


Fig. 7 Distribution of floodplain classes and difference in class with respect to baseline conditions, development scenarios, dry conditions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Change
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D7 combined
D8 abstractions
D9 damming
PF1
PF2
RF1
RF2
OF
HFO
DL
wetter by:
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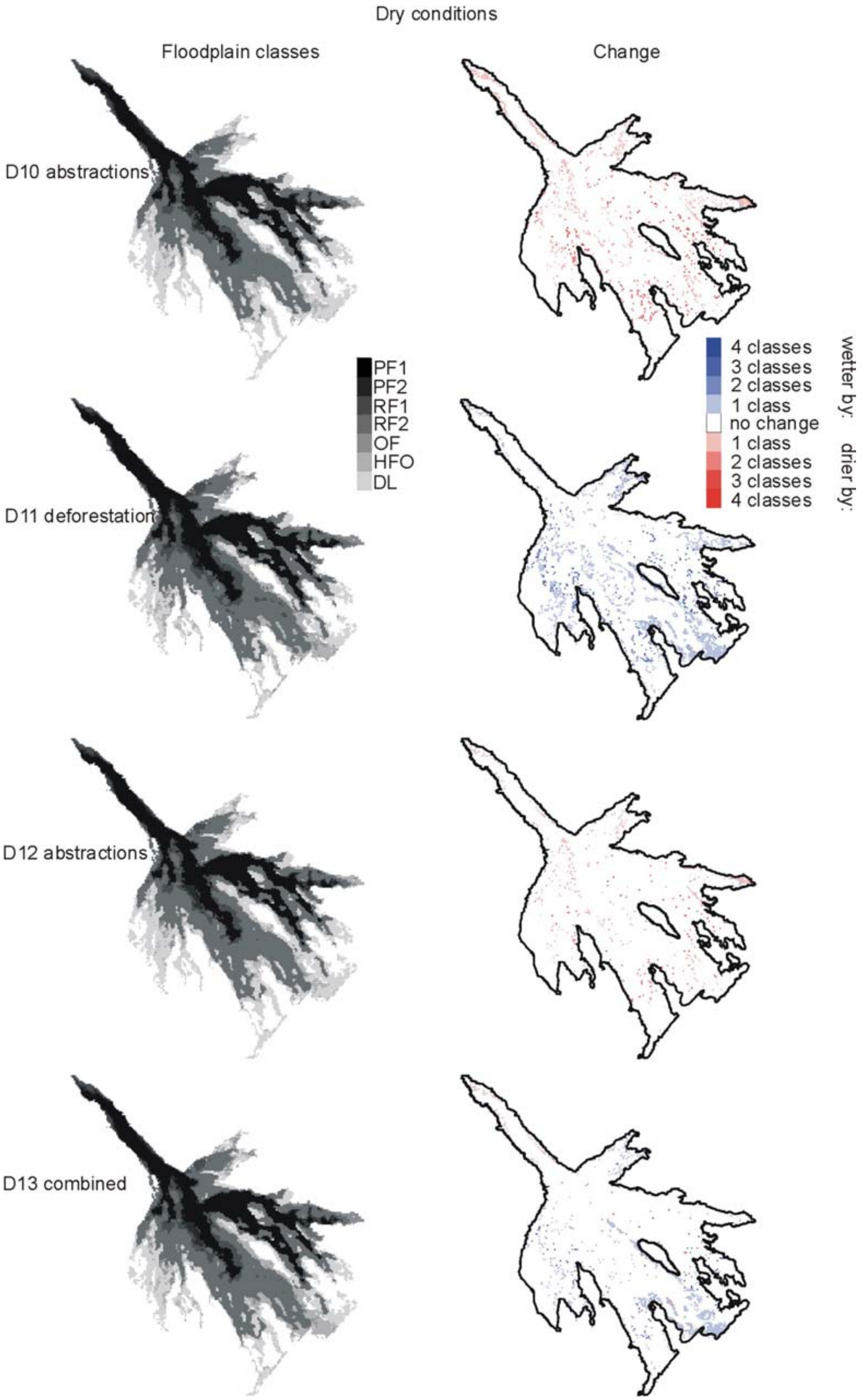
3 classes
2 classes
1 class
no change
drier by:
1 class
2 classes
3 classes
4 classes

Fig. 7 cont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OF
HFO
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3 classes
4 classes

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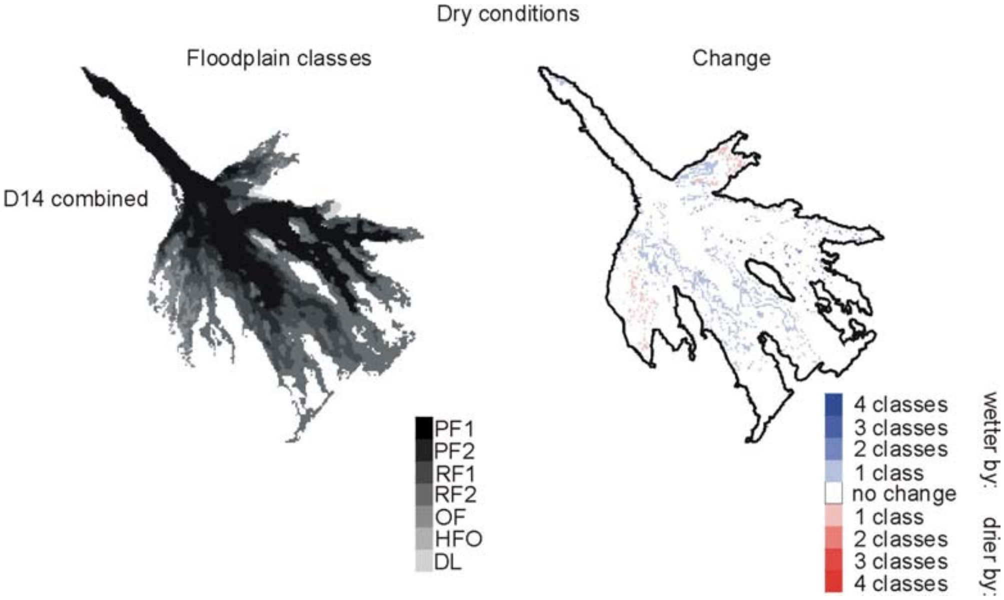
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wetter by:
drier by:

Fig. 7 cont.

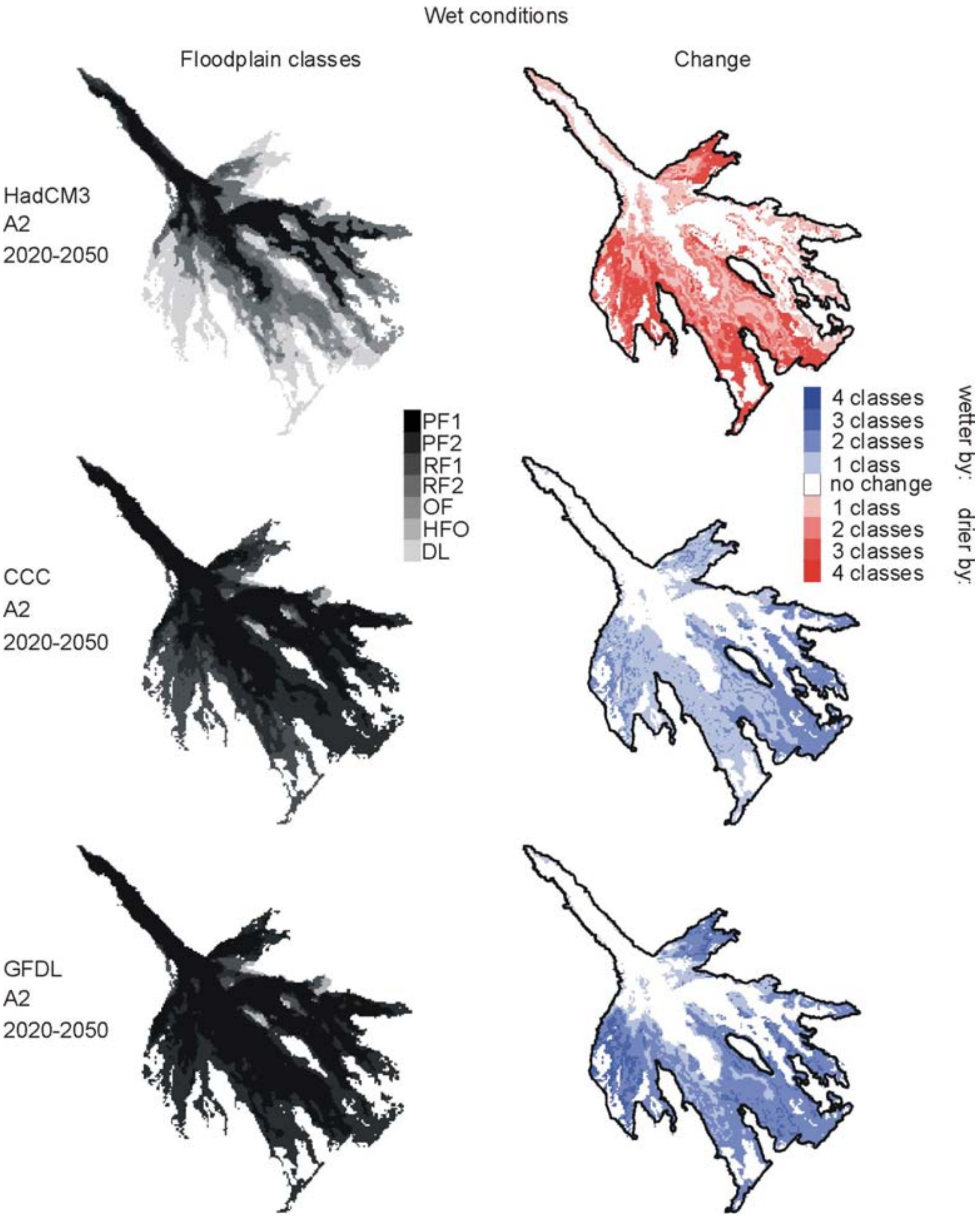
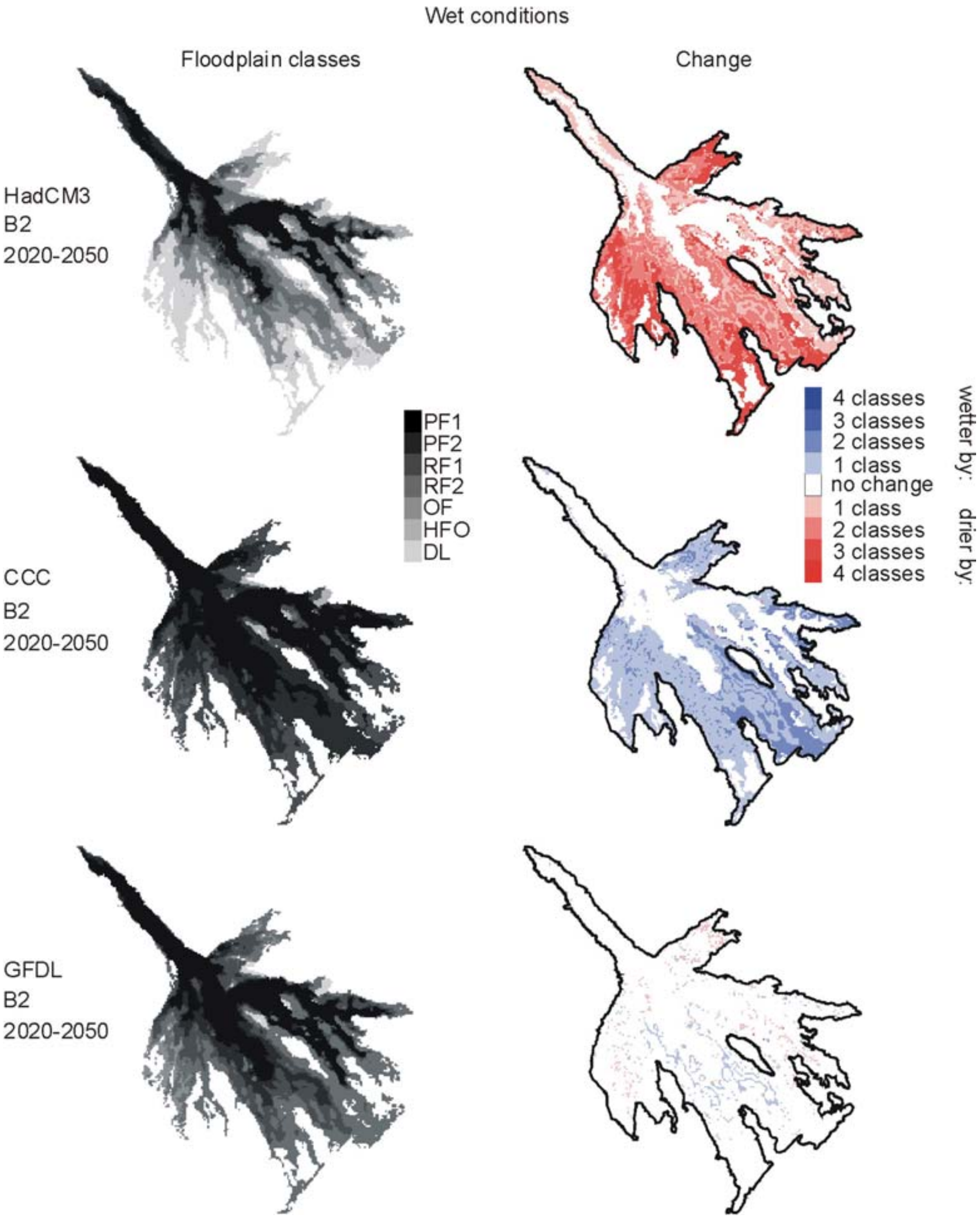


Fig. 8 Distribution of floodplain classes and difference in class with respect to baseline conditions, climate scenarios, wet conditions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B2
2020-2050
CCC
B2
2020-2050
GFDL
B2
2020-2050
PF1
PF2
RF1
RF2
OF
HFO
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wetter by:
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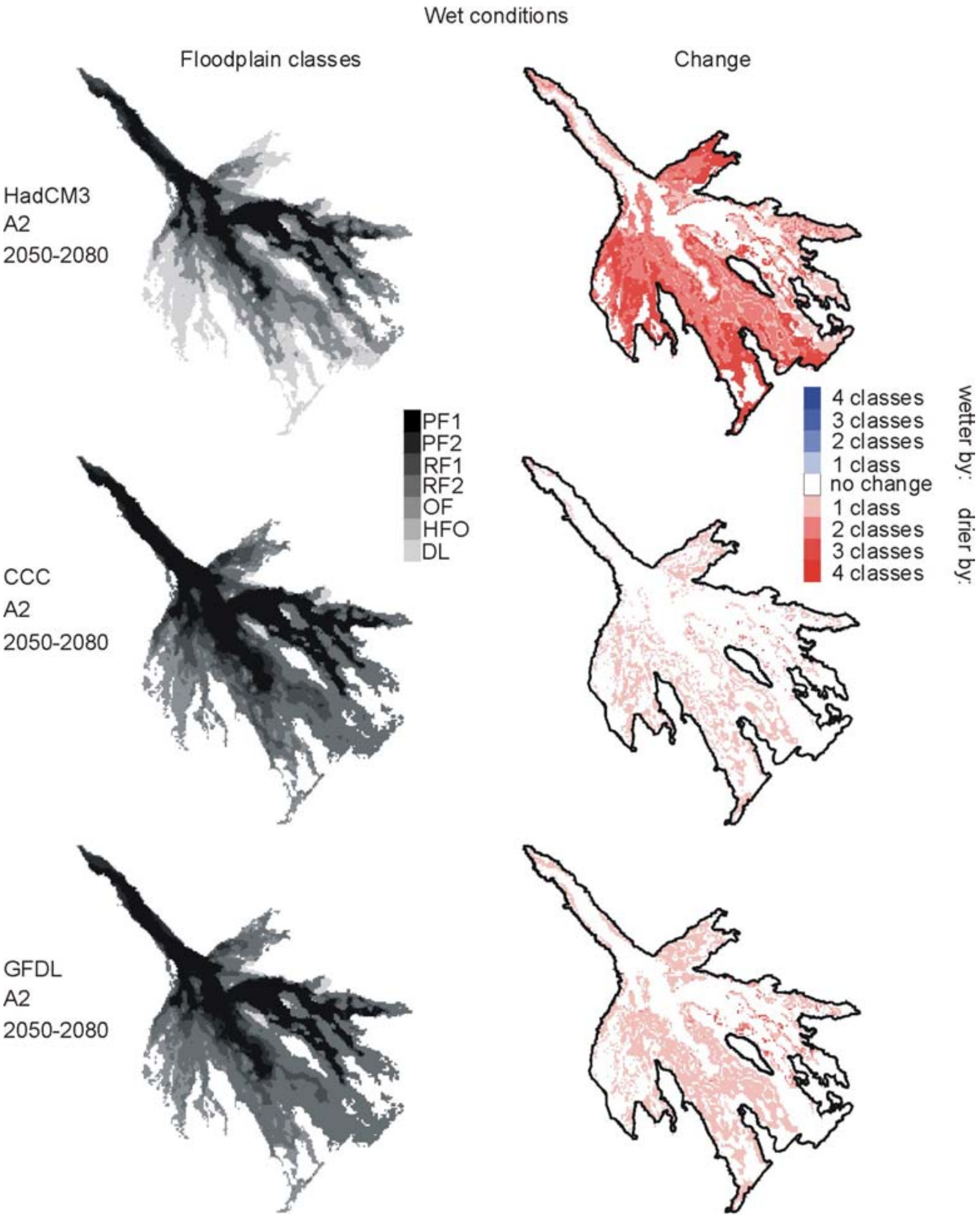
1 class
no change
1 class
2 classes
3 classes
4 classes
drier by:

Fig. 8 cont.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PF2
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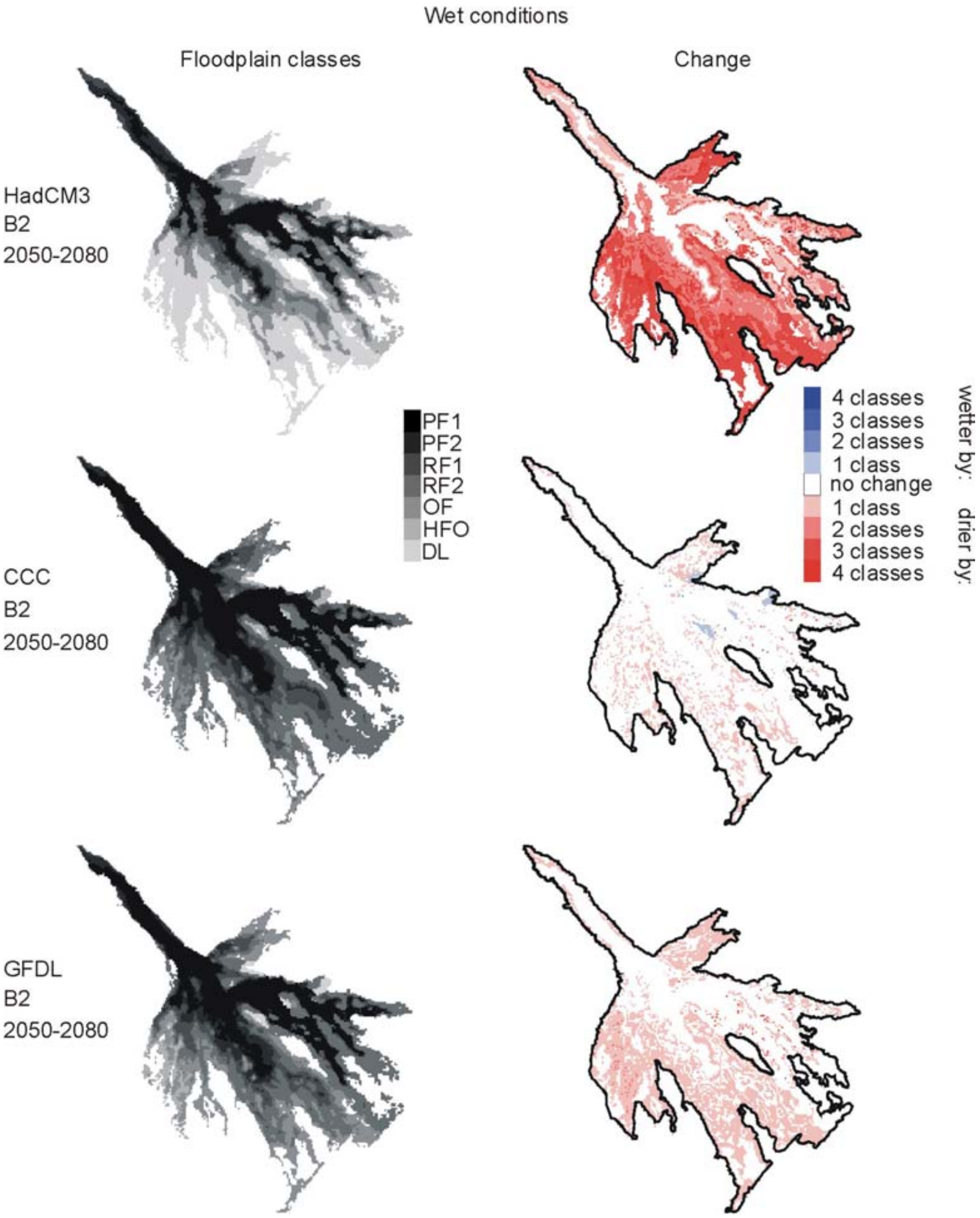
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3 classes
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drier by:

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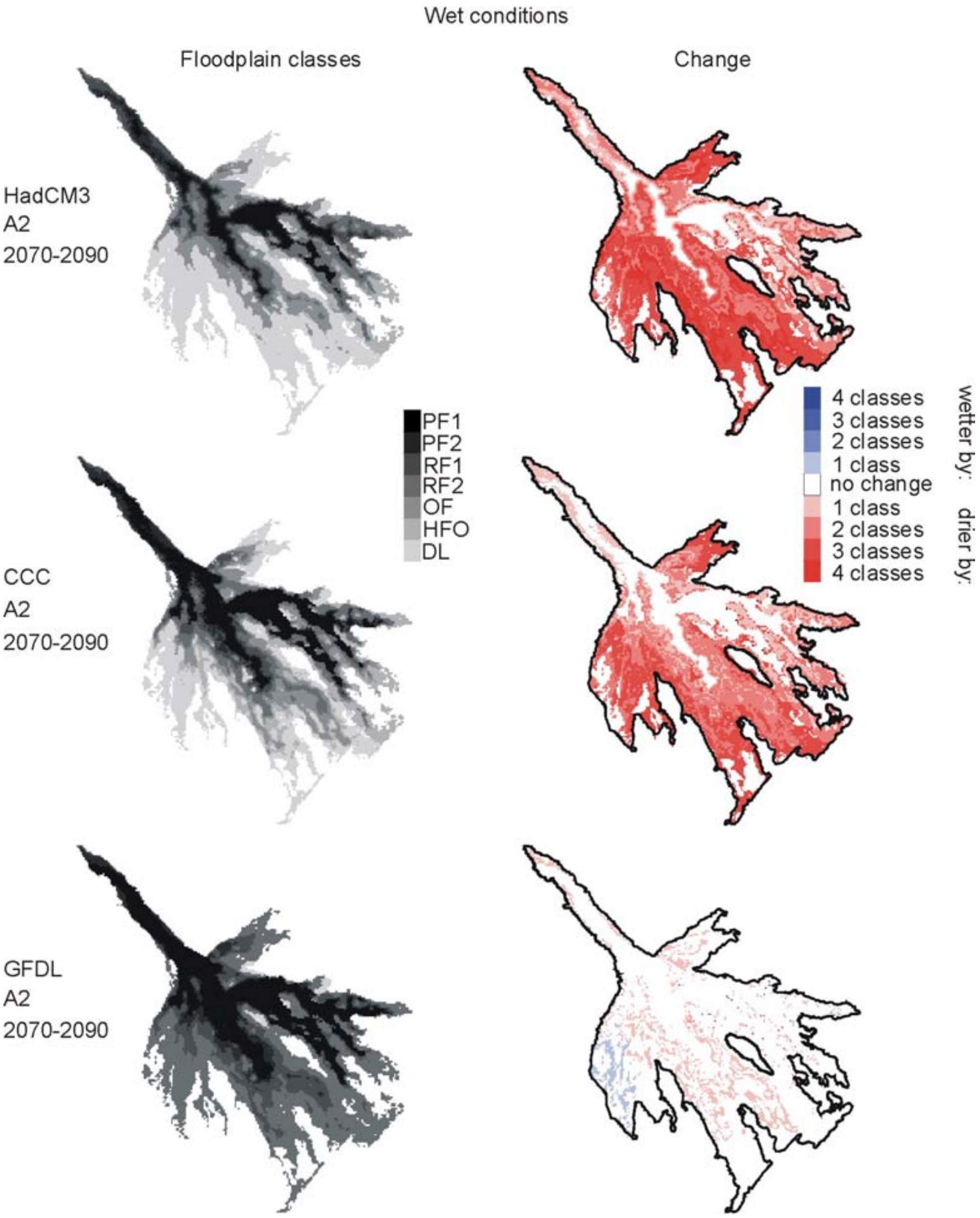
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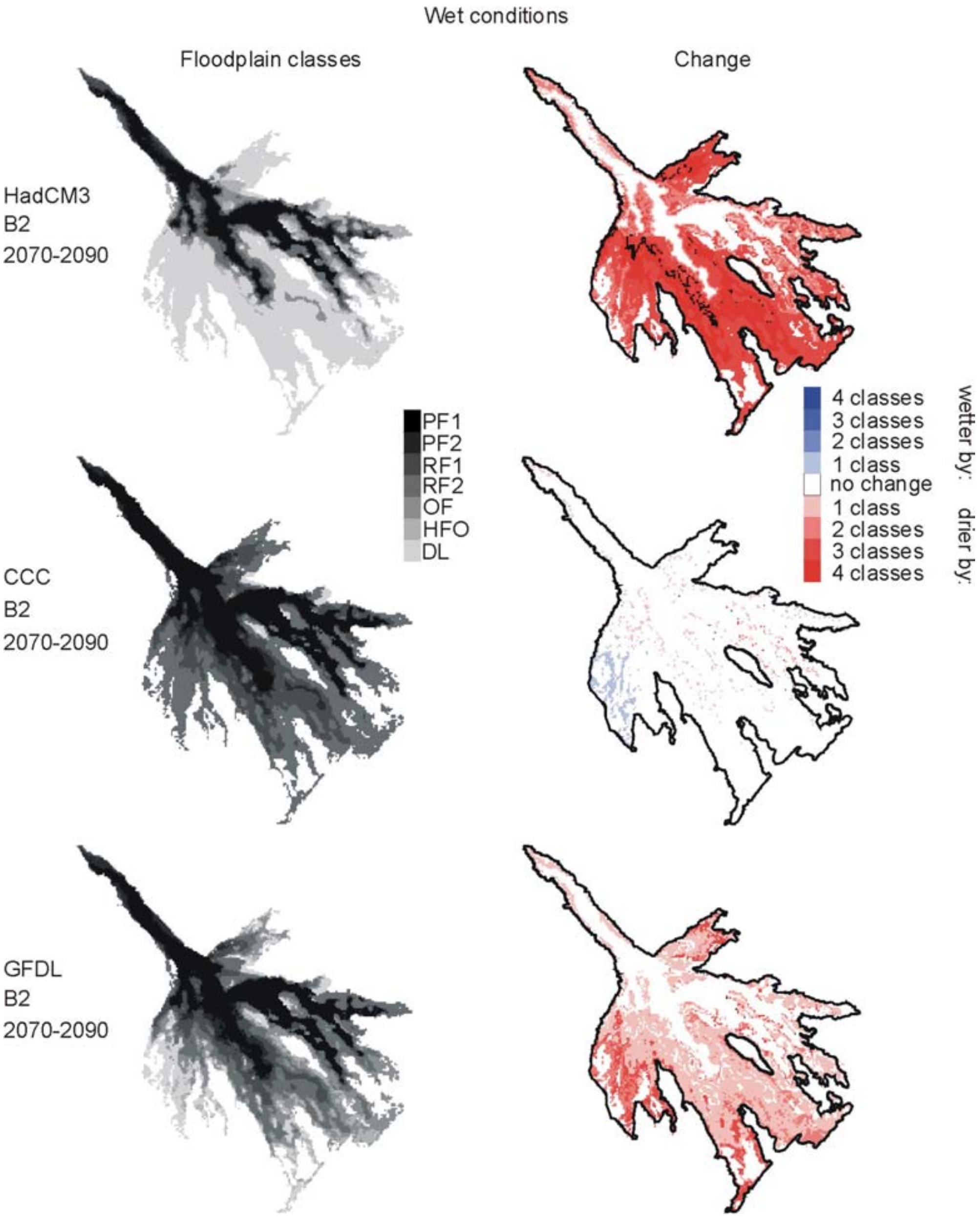
Fig. 8 cont.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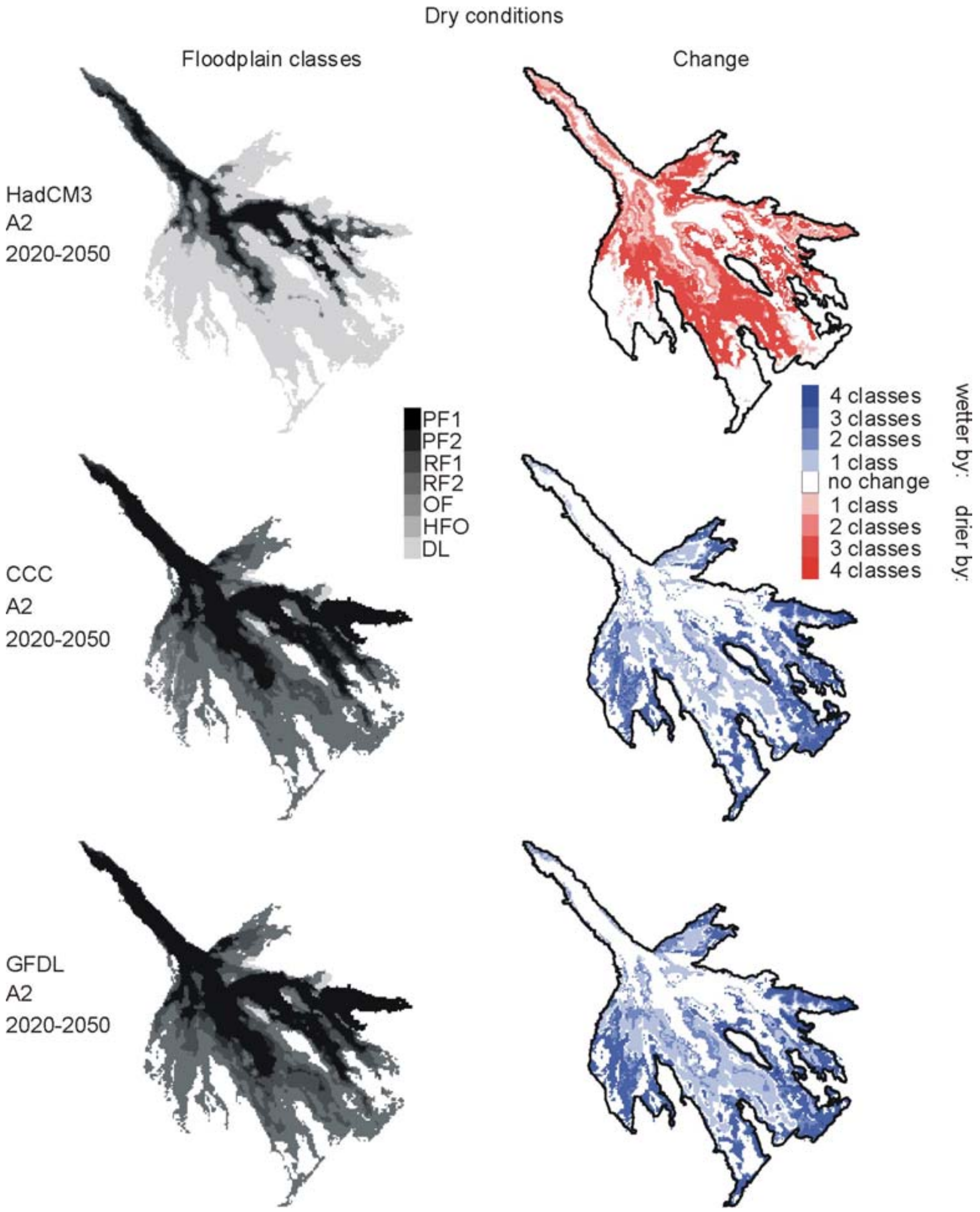

Fig. 9 Distribution of floodplain classes and difference in class with respect to baseline conditions, climate scenarios, dry conditions

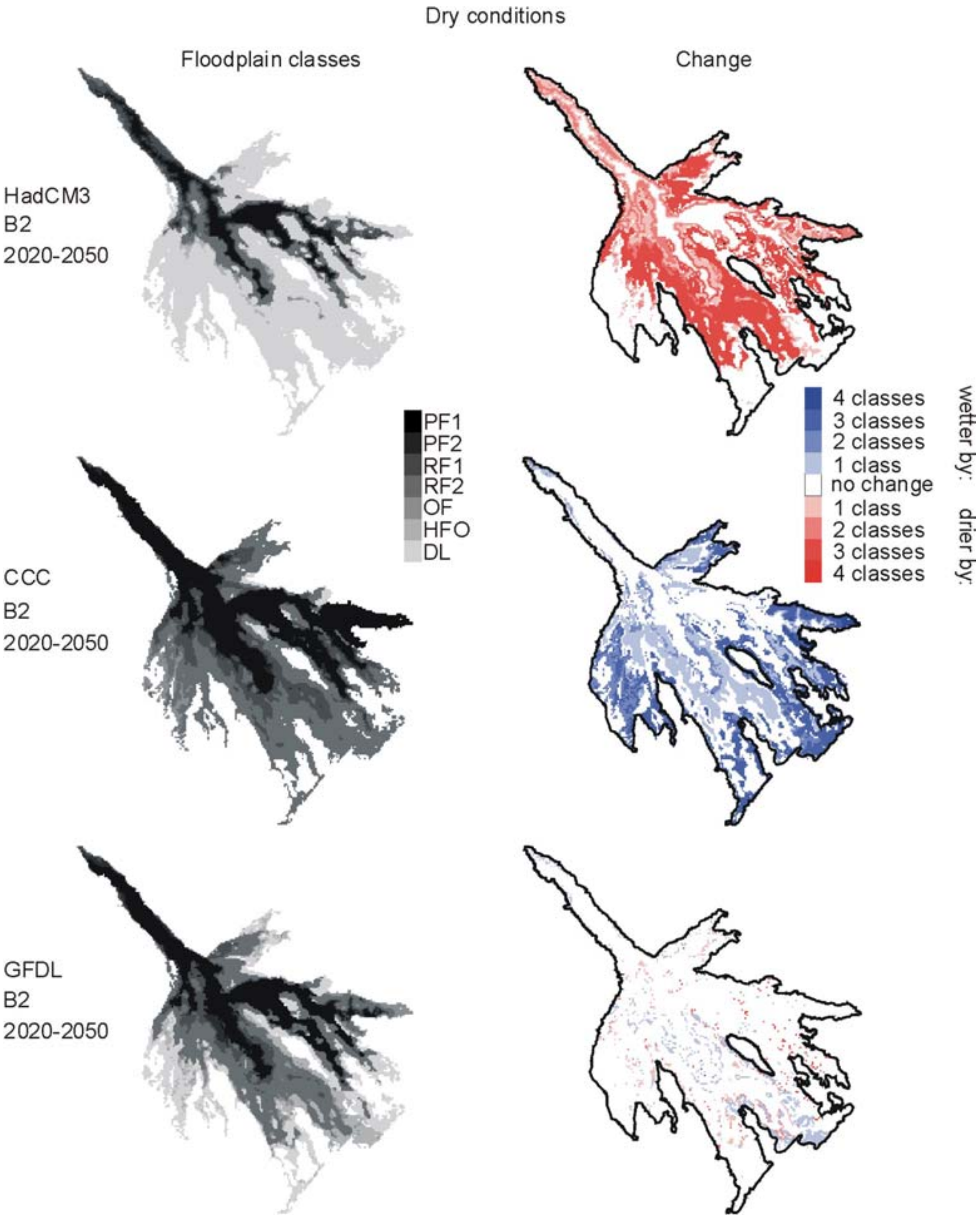
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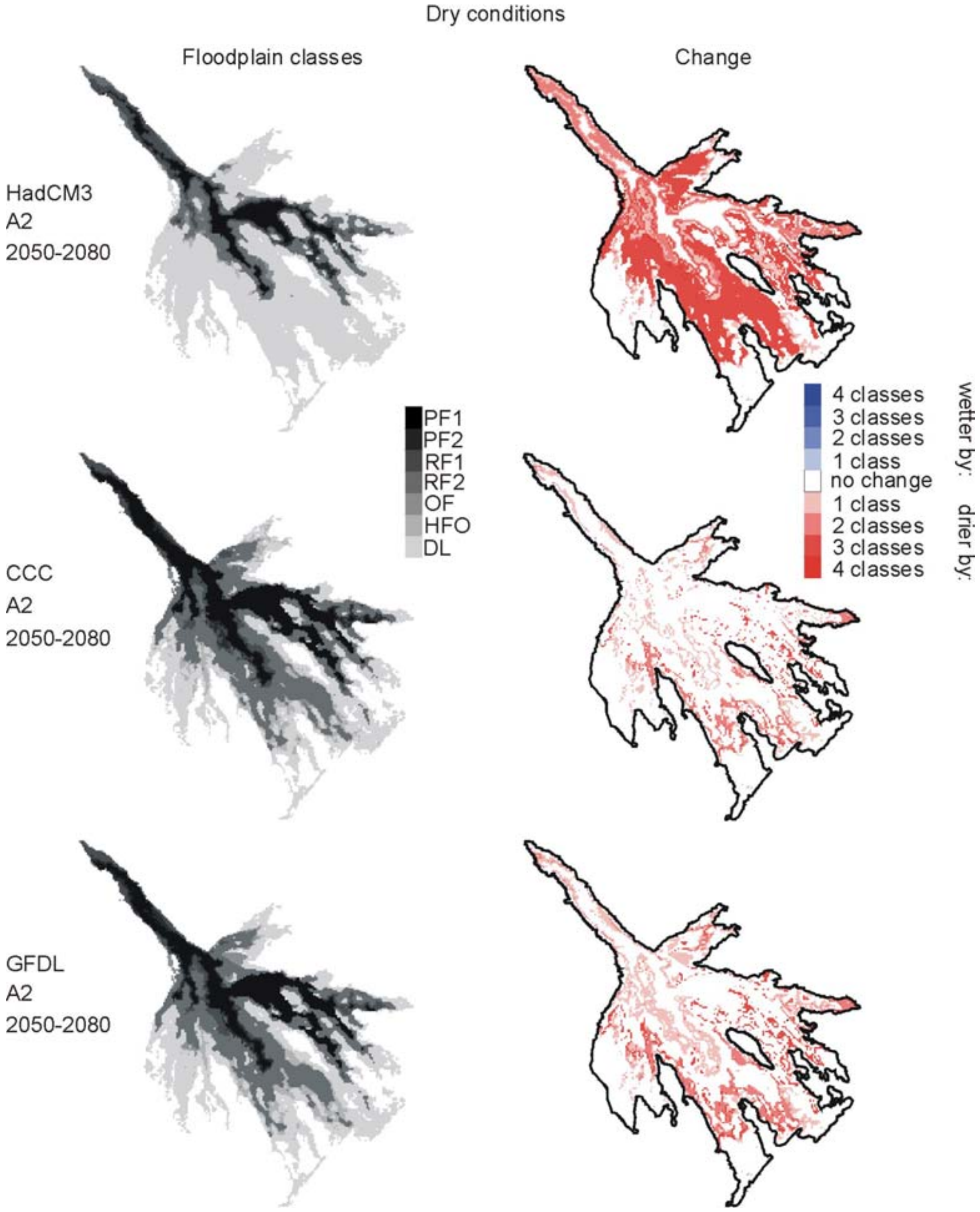
Fig. 9 cont.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drier by:

Fig. 9 cont.

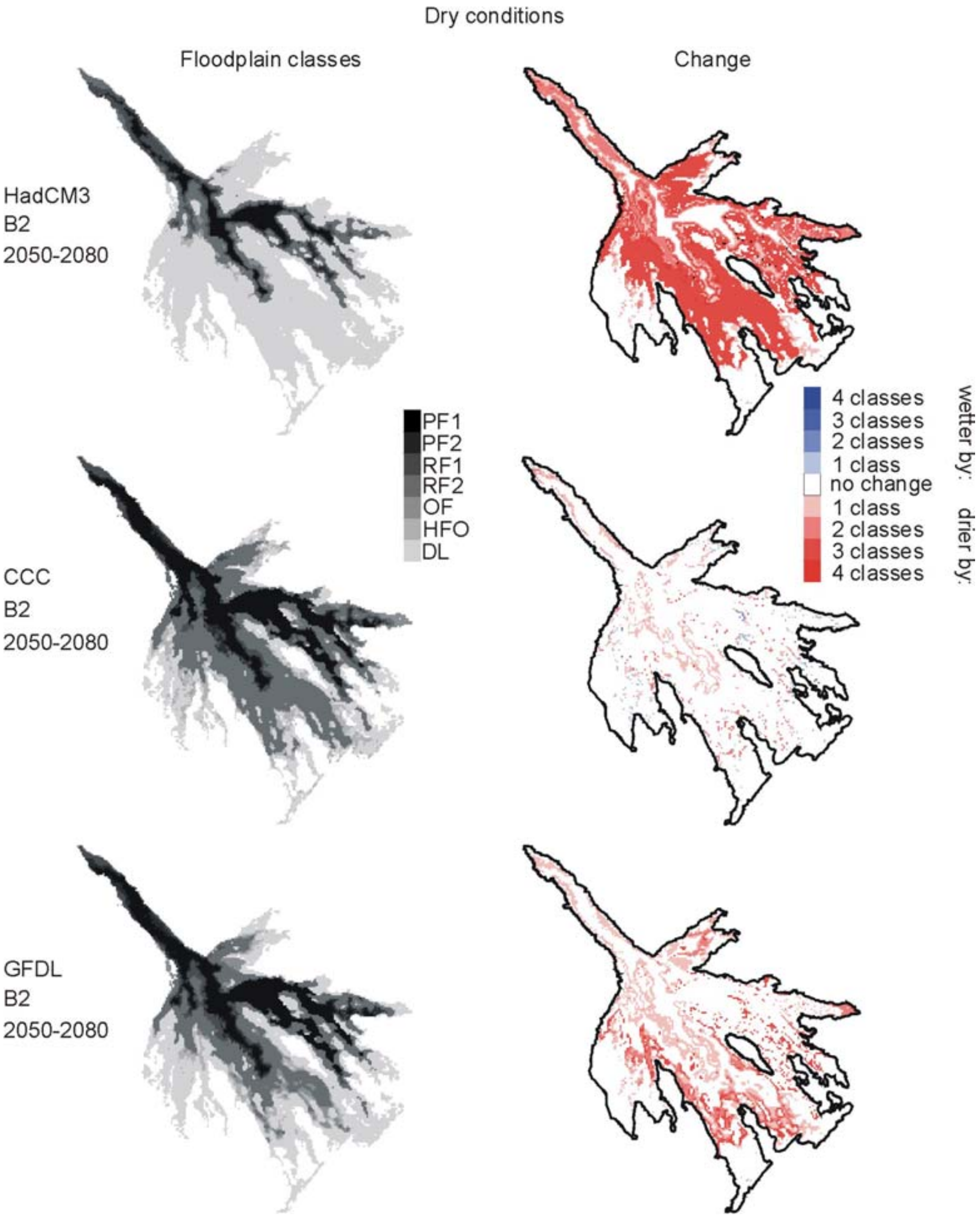
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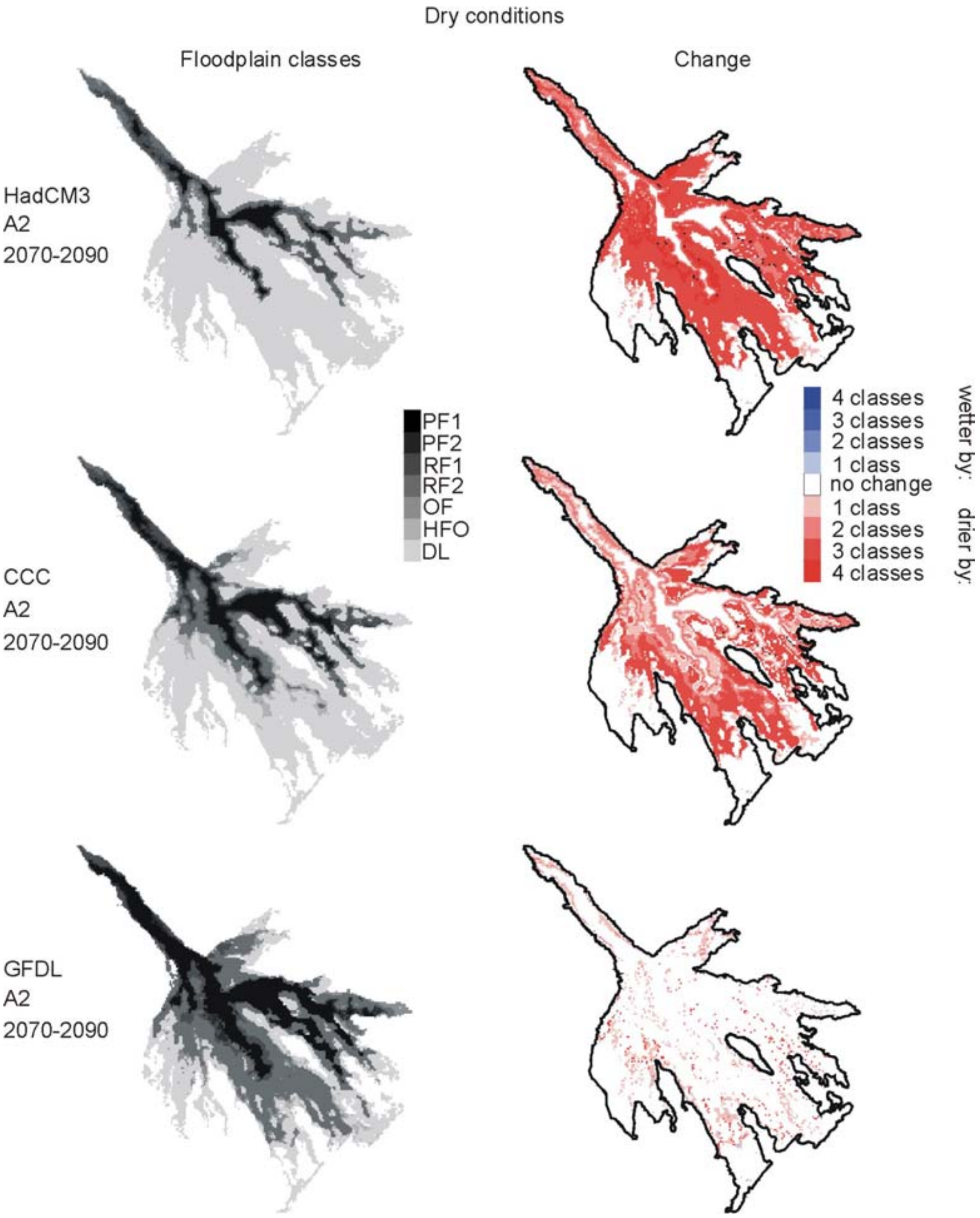
Fig. 9 cont.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2 classes
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4 classes

Fig. 9 cont.

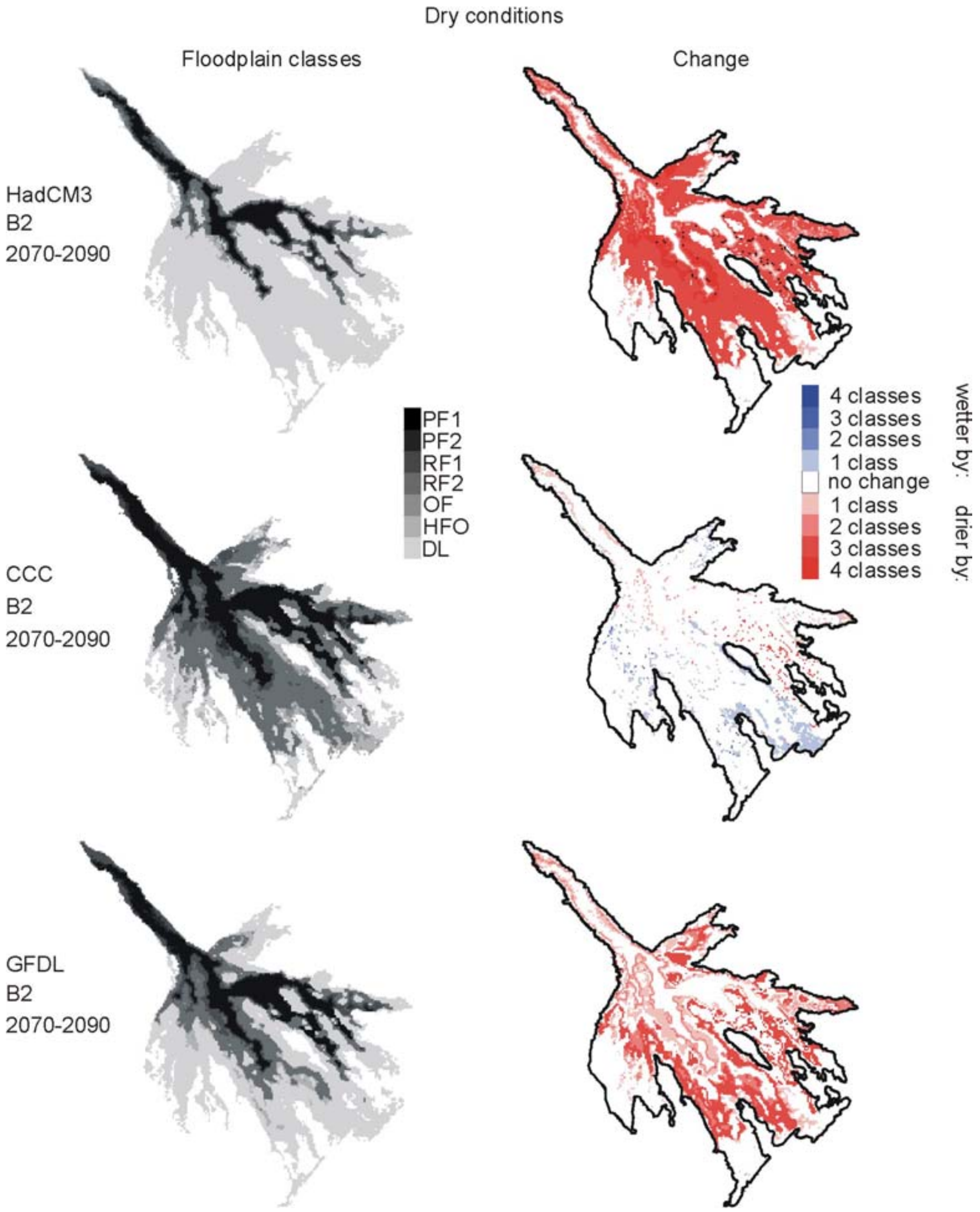
Dry conditions
Floodplain classes
Change
HadCM3
B2
2070-2090
CCC
B2
2070-2090
GFDL
B2
2070-2090
PF1
PF2
RF1
RF2
OF
HFO
DL
wetter by:
4 classes
3 classes
2 classes
1 class
no change
drier by:
1 class
2 classes
3 classes
4 classes

Fig. 9 cont.

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