Allocation of Disputable Zones in the Arctic Region

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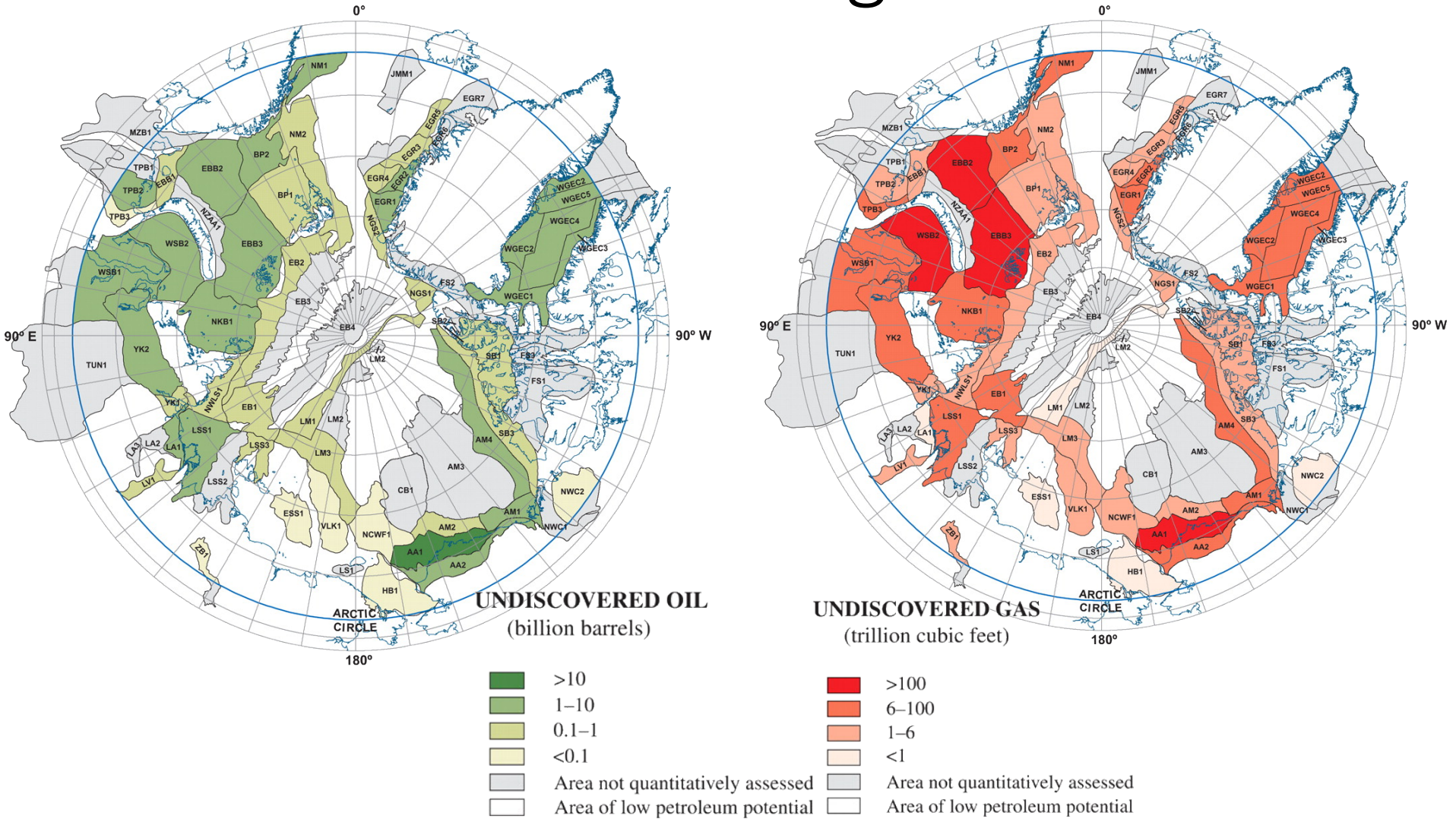
Outline

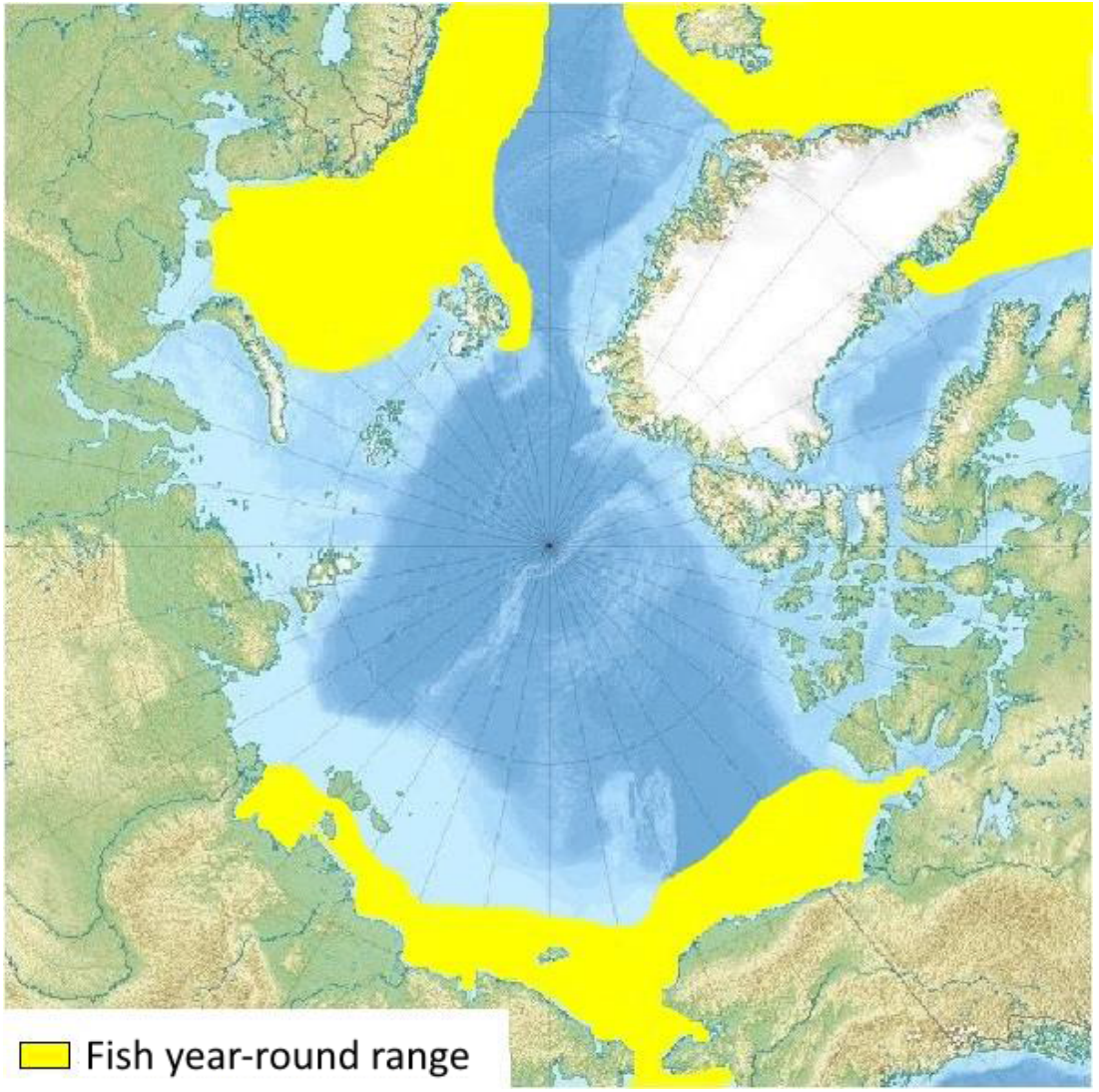
1. Arctic region ant its natural resources;
2. Countries with explicit interest in the region;
3. Analysis of disputable in the Arctic region;
4. Joint and disjoint allocation of zones.

Arctic region

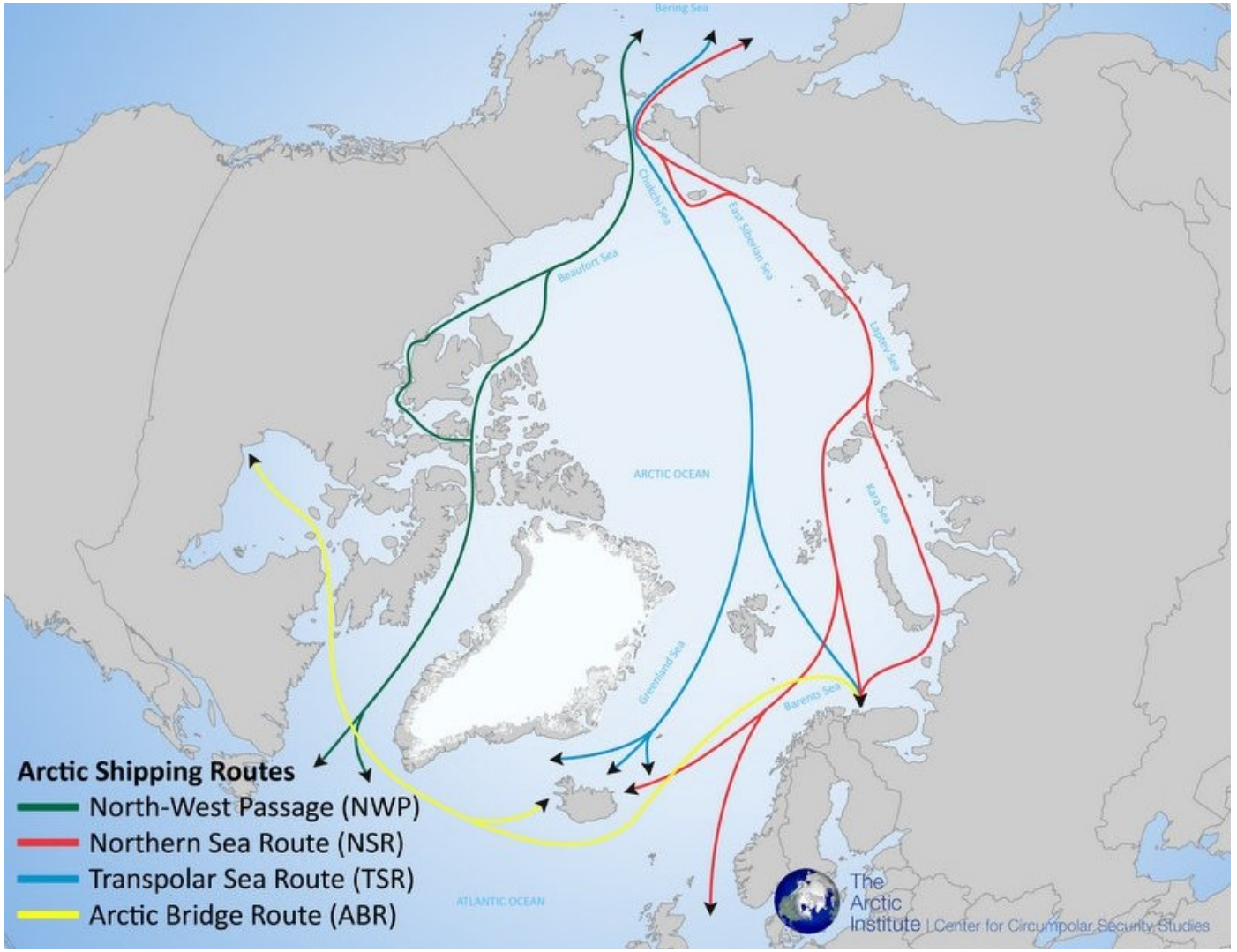
Natural resources: oil and gas



Natural resources: fish

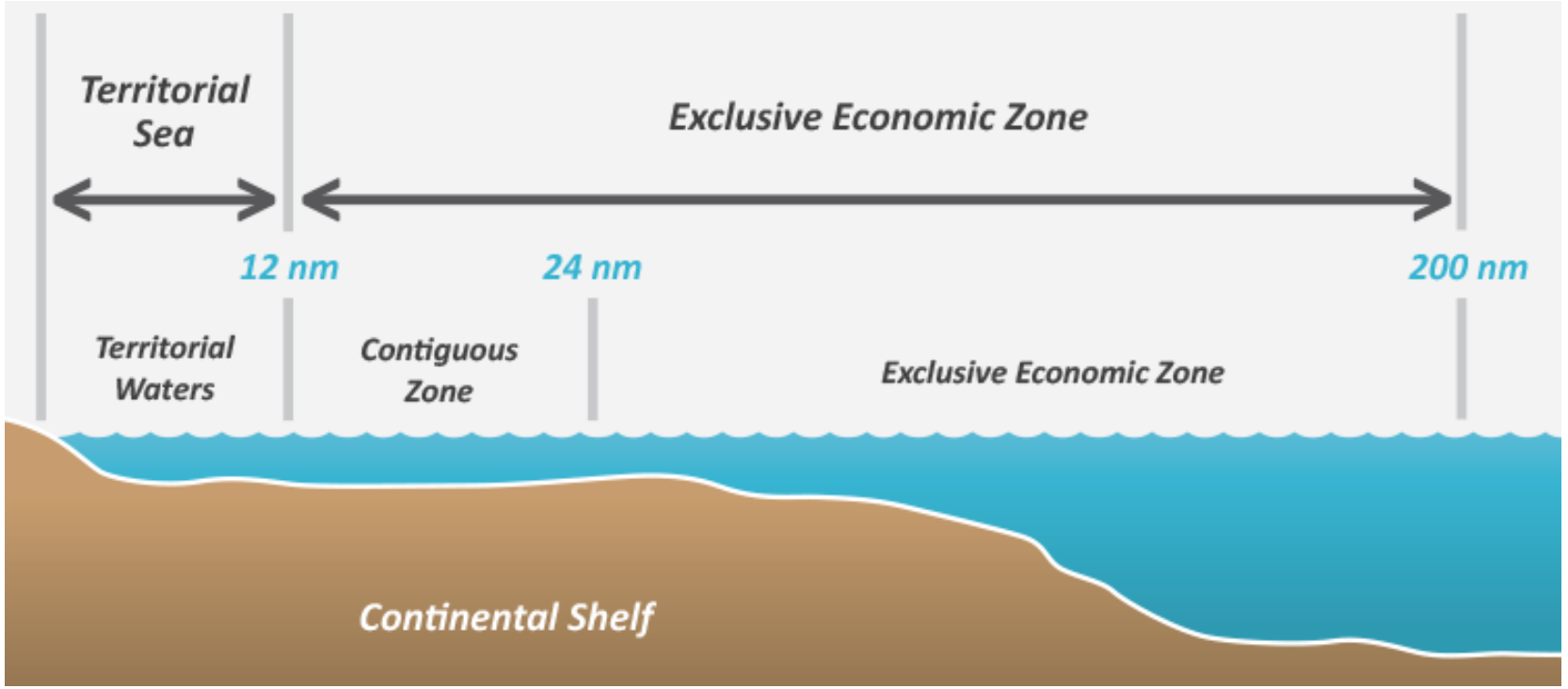


Shipping routes



Maritime international boundaries

- United Nations Convention on the Law of the Sea (UNCLOS), 1982.



Exclusive economic zones (EEZ)

- The five Arctic States – Canada, Denmark, Norway, Russia and the USA – are limited to EEZ of 200 nautical miles (≈370.4 km) adjacent to their coasts;
- EEZ gives a country exclusive rights to resources such as oil and gas;
- The waters beyond the EEZs are considered the “high seas” or international waters. The international waters are not owned by any country.

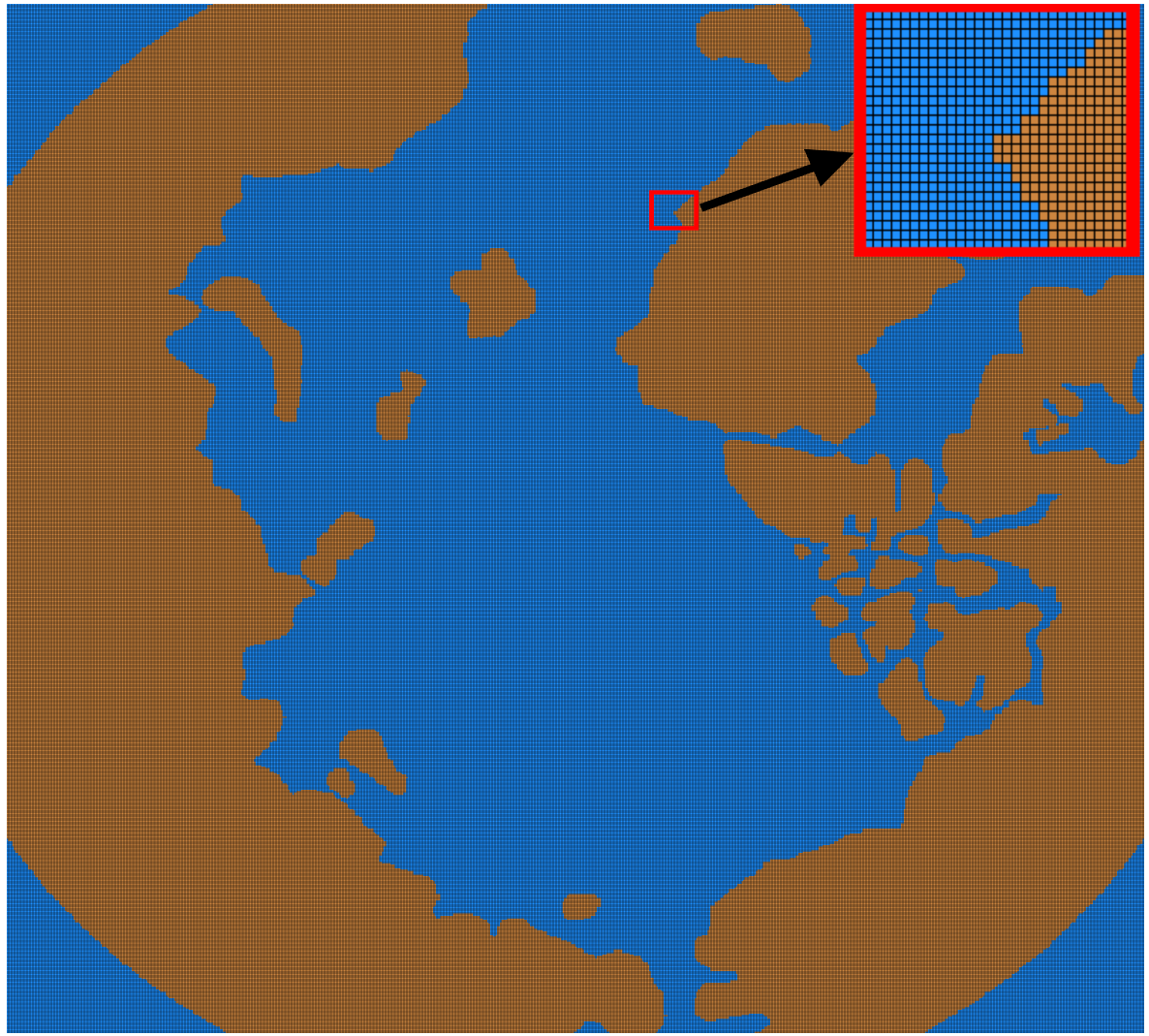
Arctic Ocean EEZ

High Sea Pockets in the Arctic

- The Banana hole (Loop Sea), around 250 000 km^2 – between Norway, Iceland, the Faroe Islands and Greenland;
- The Loop Hole, around 175 000 km^2 - between Norway and Russia (resolved in 2010);
- North of the Arctic, around 2 800 000 km^2.

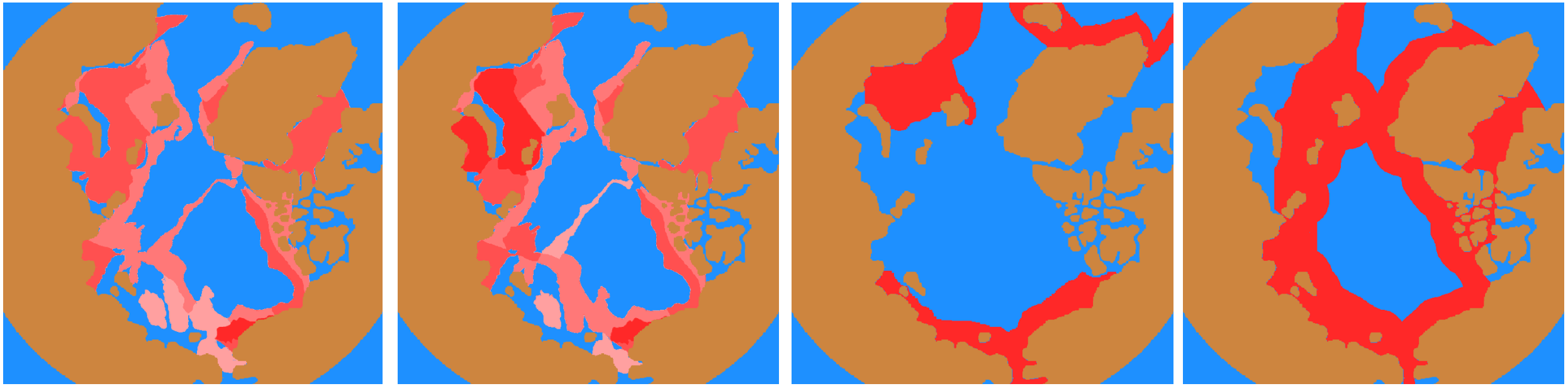
Countries under consideration

Arctic region splitting (800x800)



- Total number of areas: 640 000.
- Areas with natural resources: 59 100
- Areas not in an exclusive economic zone of a country: ≈ 9 300

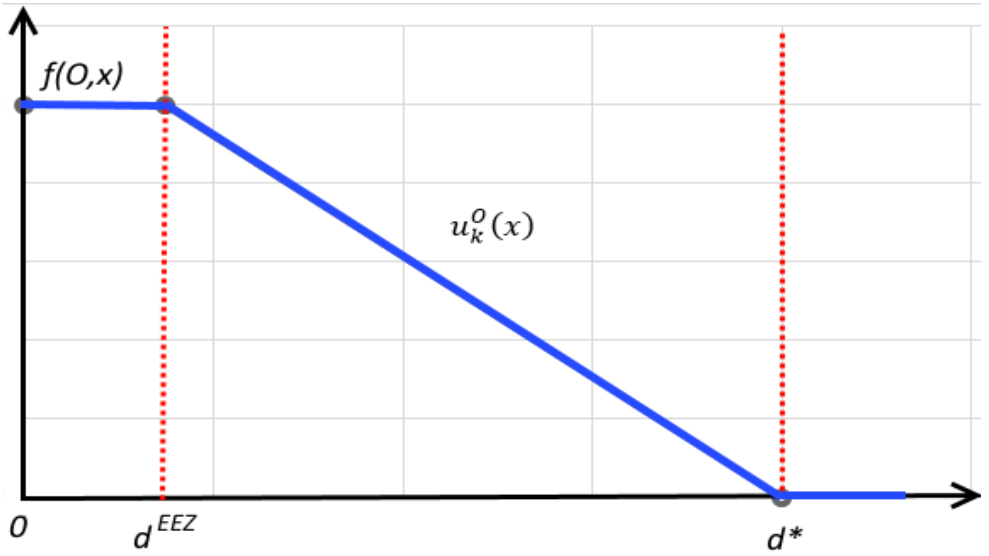
Arctic maps



Utility functions: oil

$$u_k^O(x) = \begin{cases} f(O,x) \quad if \quad d_k(x) \le d^{EEZ}, \\ f(O,x) \cdot \left(\dfrac{d^* - d_k(x)}{d^* - d^{EEZ}} \right) \quad if \quad d^{EEZ} < d_k(x) < d^*, \\ 0 \quad if \quad d_k(x) \ge d^*, \end{cases}$$

where $d_k(x)$ is the distance from the closest point of the country k to the area x, $f(O,x)$ is the volume of oil in region x, d^{EEZ} - the length of EEZ of a country, d^* - maximal distance to the area of interest.



Utility functions: gas, fish, shipping

Gas

$$u_k^G(x) = \begin{cases} f(G,x) \quad if \quad d_k(x) \le d^{EEZ}, \\ f(G,x) \cdot \left(\dfrac{d^* - d_k(x)}{d^* - d^{EEZ}} \right) \quad if \quad d^{EEZ} < d_k(x) < d^*, \\ 0 \quad if \quad d_k(x) \ge d^*, \end{cases}$$

Fish

$$u_k^F(x) = \begin{cases} f(F,x) \quad if \quad d_k(x) \le d^{EEZ}, \\ f(F,x) \cdot \left(\dfrac{d^* - d_k(x)}{d^* - d^{EEZ}} \right) \quad if \quad d^{EEZ} < d_k(x) < d^*, \\ 0 \quad if \quad d_k(x) \ge d^*, \end{cases}$$

Maritime routes

$$u_k^M(x) = f(M,x) \cdot \max\left(Imp_k, \left(\frac{d^* - d_k(x)}{d^* - d^{EEZ}} \right) \right).$$

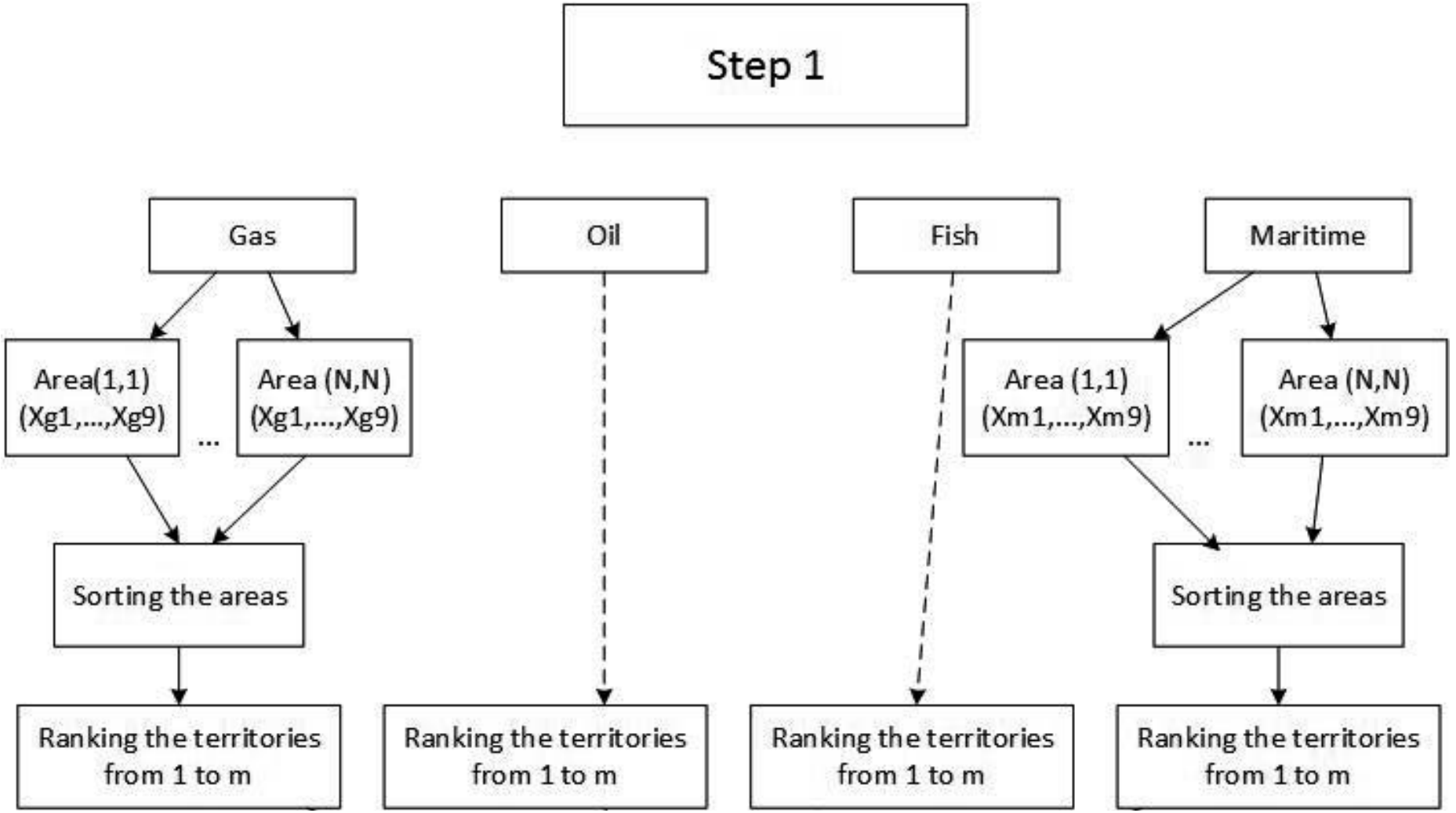
Imp_k is the importance of shipping routes in Arctic region of country k, $f(G,x), f(F,x), f(M,x)$ is the volume of gas, fish, existing of maritime routes in region x.

Analysis of disputable zones in the Arctic

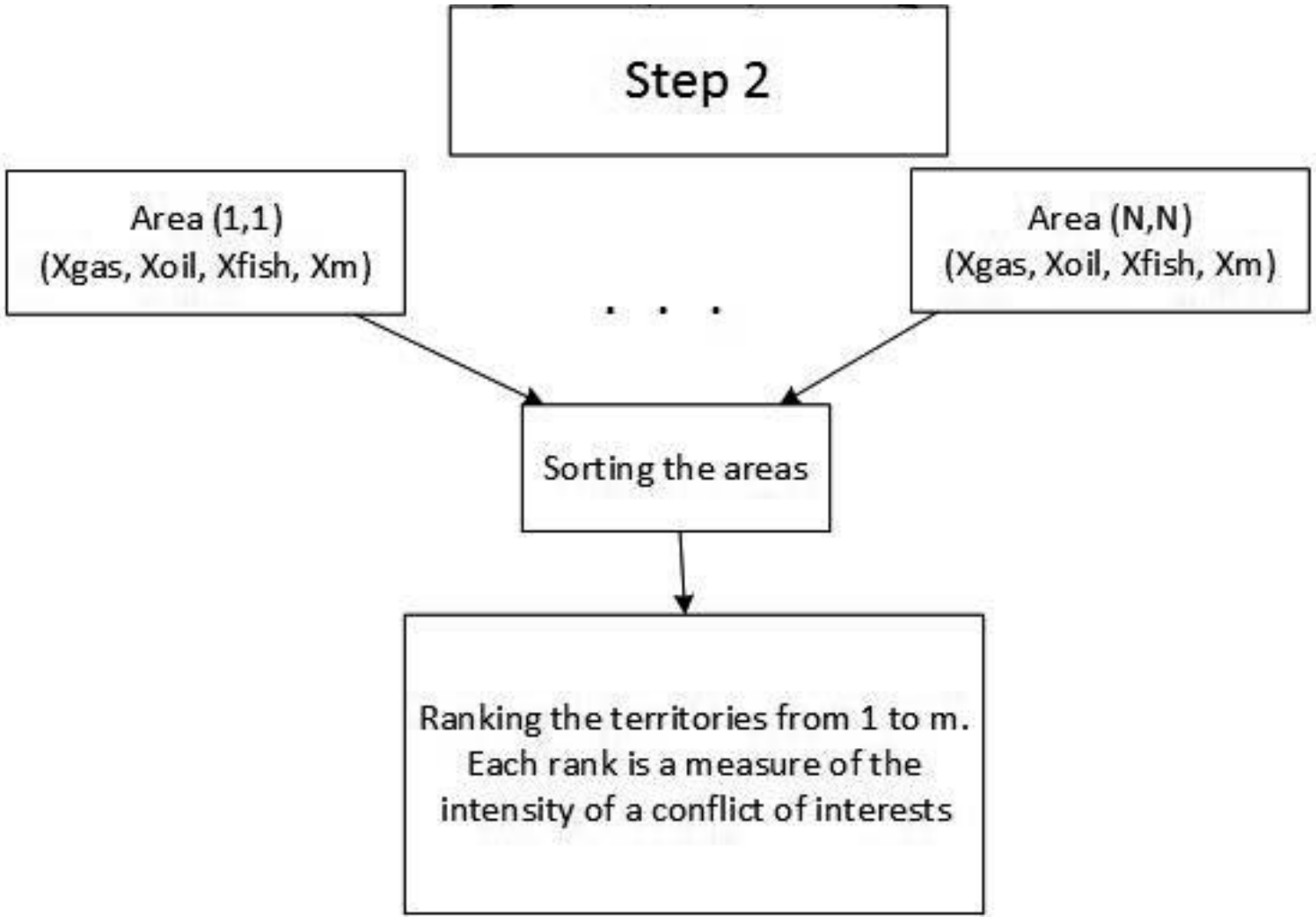
Aleskerov, F., Victorova, E. An analysis of potential conflict zones in the Arctic Region. Working paper WP7/2015/05. Moscow: HSE Publishing House, 2015.

- The intensity of potential conflict of interests in the Arctic Region is assessed;
- A model allowing to analyze preferences of the countries interested in natural resources, and reveal potential disputes among them is proposed.

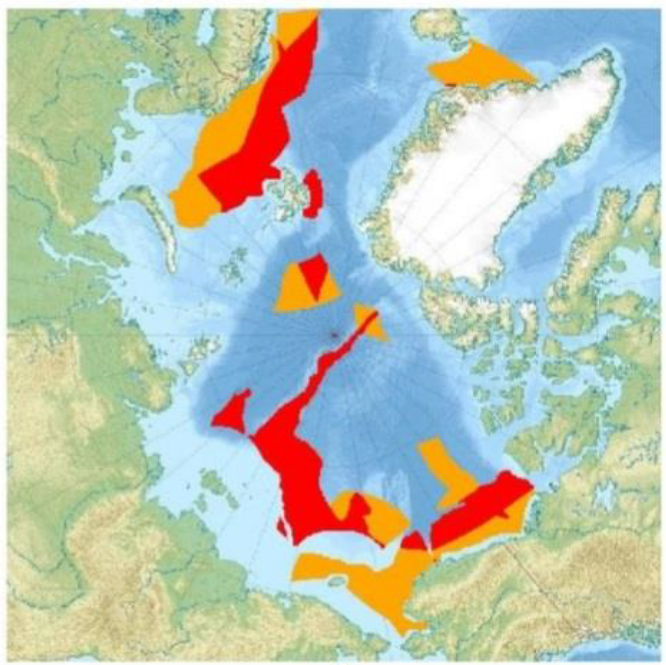
Model: step 1


Step 1
Gas
Oil
Fish
Maritime
Area(1,1)
(Xg1,...,Xg9)
...
Area (N,N)
(Xg1,...,Xg9)
Area (1,1)
(Xm1,...,Xm9)
...
Area (N,N)
(Xm1,...,Xm9)
Sorting the areas
Sorting the areas
Ranking the territories from 1 to m
Ranking the territories from 1 to m
Ranking the territories from 1 to m
Ranking the territories from 1 to m

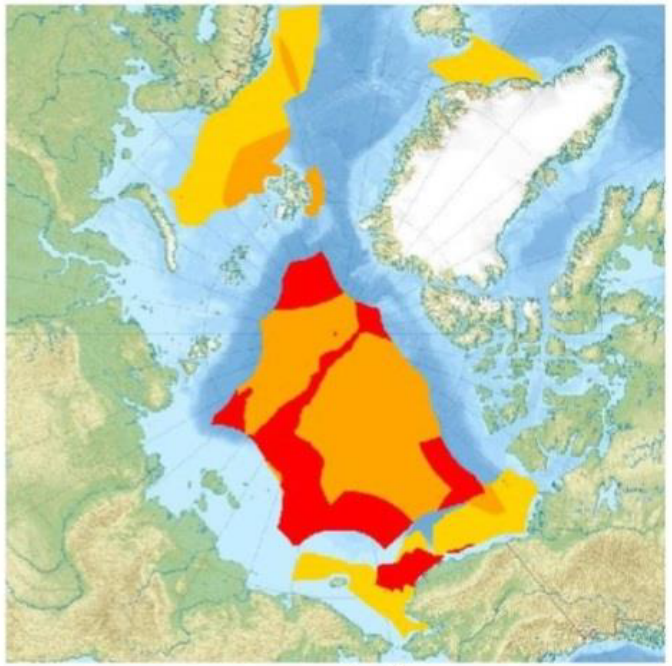
Model: step 2


Step 2
Area (1,1)
(Xgas, Xoil, Xfish, Xm)
. . .
Area (N,N)
(Xgas, Xoil, Xfish, Xm)
Sorting the areas
Ranking the territories from 1 to m.
Each rank is a measure of the
intensity of a conflict of interests

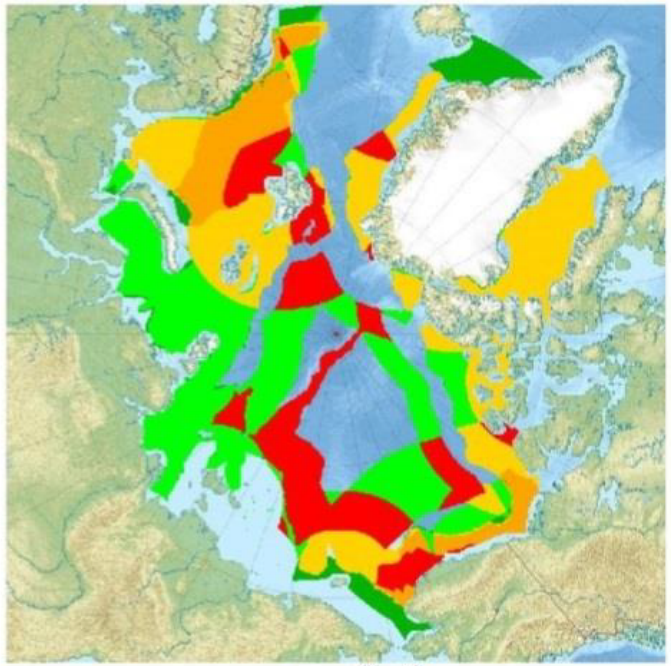
Intensities of potential conflict of interests



α = 0



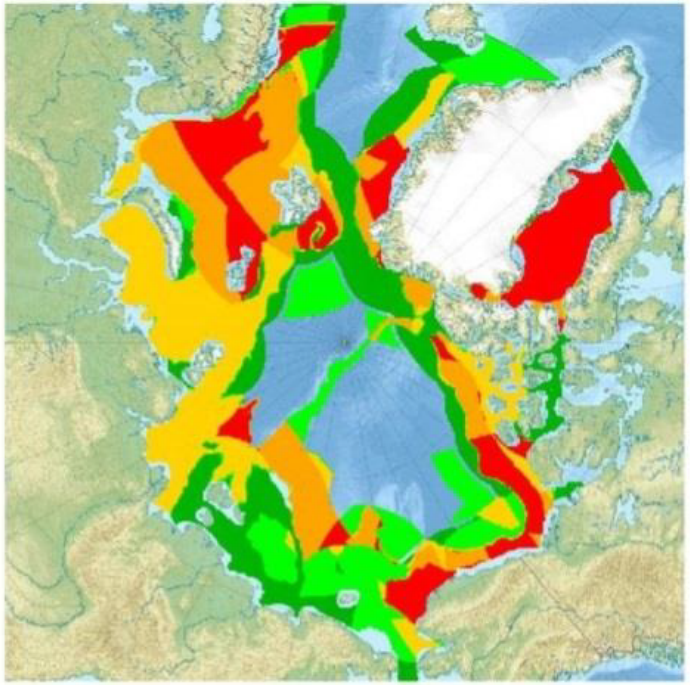
α = 0.2



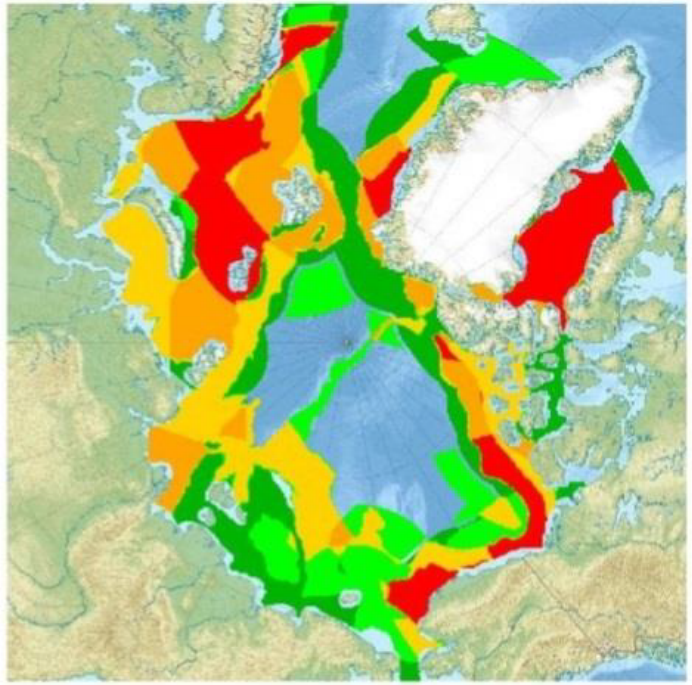
α=0.4

α is the level of interest in natural resources located in EEZ of other countries.

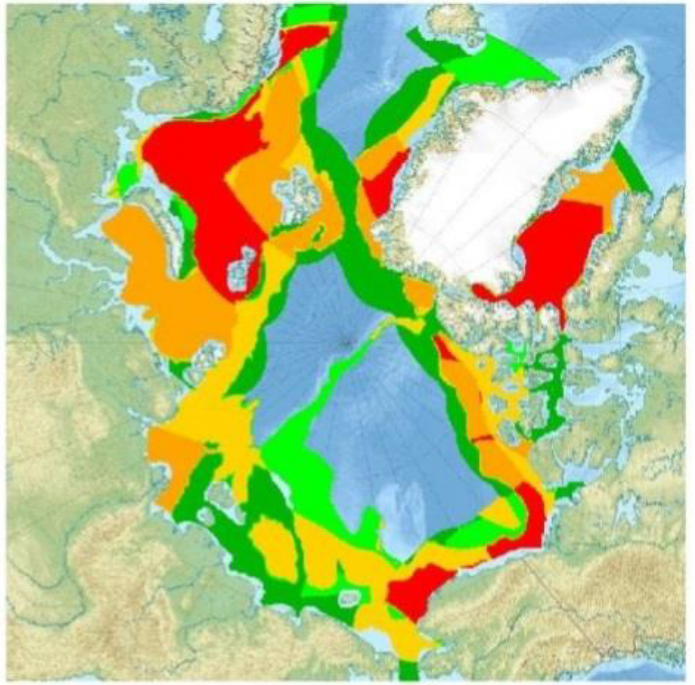
Intensities of potential conflict of interests



α=0.6



α=0.8

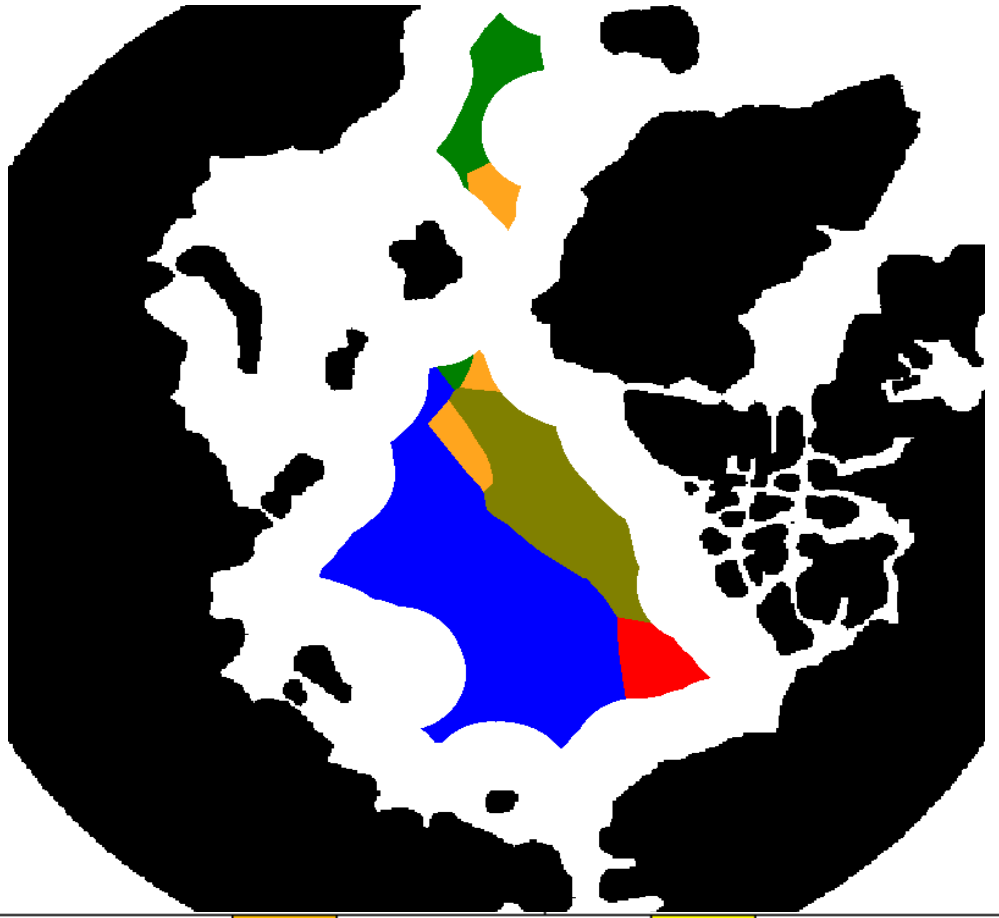


α=1

α is the level of interest in natural resources located in EEZ of other countries.

Arctic Ocean EEZ

Allocation by distance



	USA		Denmark		China
	Russia		Norway		Japan
	Canada		Iceland		Republic of Korea

Satisfaction level

$$S_k\left(P_{l_1}\right) = \sum_{x \in X : (x,k) \in P_{l_1}} \left(u_k^T(x)\right) - \sum_{x \in X : (x,k) \notin P_{l_1}} \left(u_k^T(x)\right)$$

Allocation by distance

	USA		Denmark		China
	Russia		Norway		Japan
	Canada		Iceland		Republic of Korea

Allocation by distance (satisfaction level)

Country	Scenario 1	
	Satisfaction level	Allocated areas
USA	-6224	21
Russia	6161	7512
Canada	-6016	790
Denmark	-6819	96
Norway	-4171	862
Iceland	-2607	0
China	0	0
Japan	-791	0
South Korea	-10	0
TOTAL	-20477	9281

Envy-freeness

Country in row envies country in column	USA	Russia	Canada	Denmark	Norway	Iceland	China	Japan	South Korea	Envy-freeness
USA	0	-5825	-343	-1	28	28	28	28	28	**-5825**
Russia	7805	0	7287	7754	6795	7827	7827	7827	7827	**0**
Canada	573	-5268	0	529	-49	600	600	600	600	**-5268**
Denmark	67	-5161	-510	0	-962	85	85	85	85	**-5161**
Norway	1209	-3560	701	1138	0	1220	1220	1220	1220	**-3560**
Iceland	-4	-1142	-274	-58	-1130	0	0	0	0	**-1142**
China	0	0	0	0	0	0	0	0	0	**0**
Japan	-6	-784	0	0	0	0	0	0	0	**-784**
South Korea	0	-10	0	0	0	0	0	0	0	**-10**

Allocation of zones in Arctic region

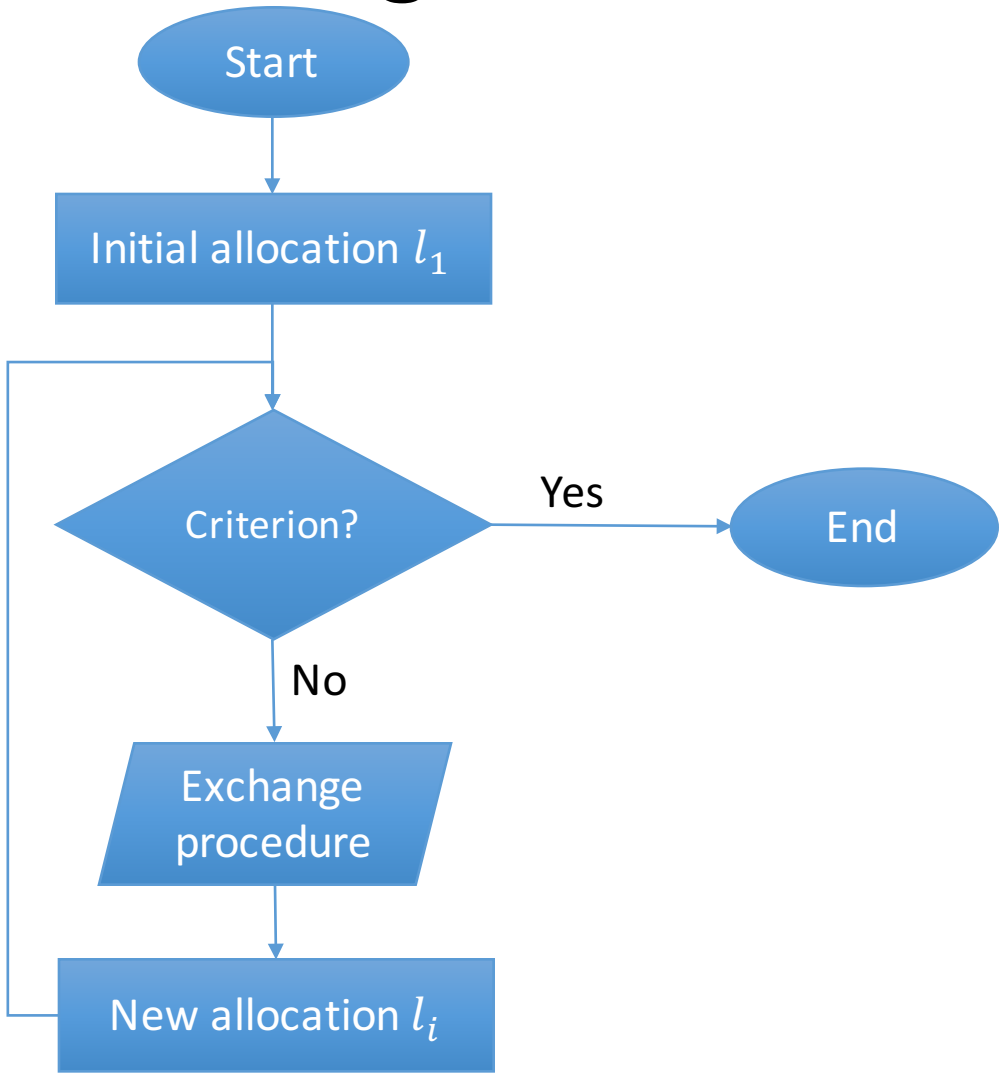
Model:

1. Some initial allocation l_1 of each area to a particular country is given;
2. Calculate the total satisfaction level

$$S_k(P_{l_1}) = \sum_{x \in X:(x,k) \in P_{l_1}} \left(u_k^T(x)\right) - \sum_{x \in X:(x,k) \notin P_{l_1}} \left(u_k^T(x)\right);$$

3. Exchange procedure: re-assignment of an area from one country to another one based on the total satisfaction level.

Allocation of zones: algorithm



Scenarios

Initial allocation:

1. All areas of Arctic region are allocated to the closest country to that area;
2. All areas of Arctic region are allocated randomly;
3. All areas of Arctic region are allocated to countries most interested in terms of utility in them;
4. All areas of Arctic region are allocated to a country interested in that region (except EEZ).

In total, 12 initial allocations.

Criteria to terminate the exchange procedure:

1. Maximization of the total satisfaction level.
2. Maximization of the satisfaction level of the most unsatisfied country.

Scenarios

- **Scenario №1.** allocation by the distance to the area.
- **Scenario №2.** *Initial allocation* by the distance.
- **Scenario №3.** *Initial allocation*: allocation of all areas to the 1st country (USA).
- **Scenario №4.** *Initial allocation*: allocation of all areas to the 2nd country (Russia).
- **Scenario №5.** *Initial allocation*: allocation of all areas to the 3rd country (Canada).
- **Scenario №6.** *Initial allocation*: allocation of all areas to the 4rd country (Norway).
- **Scenario №7.** *Initial allocation*: allocation of all areas to the 5rd country (Denmark).
- **Scenario №8.** *Initial allocation*: allocation of all areas to the 6rd country (Iceland).

Scenario 1: allocation by distance

	USA		Denmark		China
	Russia		Norway		Japan
	Canada		Iceland		Republic of Korea

Scenario 2

	USA		Denmark		China
	Russia		Norway		Japan
	Canada		Iceland		Republic of Korea

Other scenarios

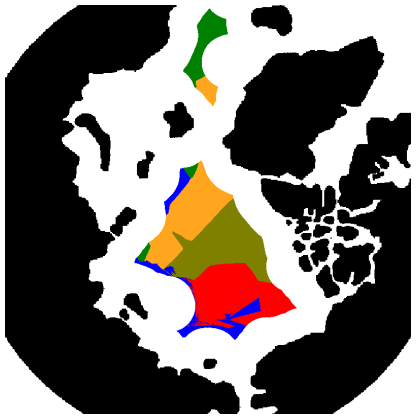
Scenario 3

Scenario 4

Scenario 5

Scenario 6

Scenario 7



Scenario 8

	USA		Denmark		China
	Russia		Norway		Japan
	Canada		Iceland		Republic of Korea

Total satisfaction level

Statistics for scenarios		Countries									TOTAL
		USA	Russia	Canada	Denmark	Norway	Iceland	China	Japan	South Korea	
Total satisfaction level	Scenario 1	-3478	-3478	-3478	-3478	-3478	-2607	0	-791	-10	-20799
	Scenario 2	-3458	-3458	-3458	-3458	-3458	-2607	0	-791	-10	-20697
	Scenario 3	-3478	-3478	-3478	-3478	-3478	-2607	0	-791	-10	-20799
	Scenario 4	-3431	-3431	-3431	-3431	-3430	-2607	0	-791	-10	-20561
	Scenario 5	-3473	-3473	-3473	-3473	-3473	-2607	0	-791	-10	-20774
	Scenario 6	-3423	-3424	-3424	-3424	-3424	-2607	0	-791	-10	-20527
	Scenario 7	-3496	-3497	-3496	-3497	-3497	-2607	0	-791	-10	-20891
	Scenario 8	-3500	-3500	-3501	-3501	-3500	-2607	0	-791	-10	-20908

Number of allocated area (with resources)

Statistics for scenarios		Countries									TOTAL
		USA	Russia	Canada	Denmark	Norway	Iceland	China	Japan	South Korea	
Number of allocated areas	Scenario 1	1568	2096	2128	2288	1201	0	0	0	0	9281
	Scenario 2	1537	2161	2026	2349	1208	0	0	0	0	9281
	Scenario 3	1568	2096	2128	2288	1201	0	0	0	0	9281
	Scenario 4	1520	2031	2019	2452	1259	0	0	0	0	9281
	Scenario 5	1580	2081	2127	2290	1203	0	0	0	0	9281
	Scenario 6	1505	2108	1915	2496	1257	0	0	0	0	9281
	Scenario 7	1534	2210	2127	2221	1189	0	0	0	0	9281
	Scenario 8	1482	2276	2132	2210	1181	0	0	0	0	9281

Superposition Allocation Model to the Most Interested Country

№	Sequence of countries
Scenario 9	Japan → Republic of Korea → Denmark → USA → Iceland → China → Canada → Norway → Russia
Scenario 10	Russia → Denmark → Japan → Iceland → Canada → Norway → Republic of Korea → China → USA
Scenario 11	Russia → China → Republic of Korea → Japan → USA → Iceland → Canada → Norway → Denmark
Scenario 12	China → USA → Denmark → Iceland → Canada → Japan → Norway → Republic of Korea → Russia

Modified Adjusted Winner Procedure

Main Stages:

1) Divide a group of countries into two equal subgroups;
2) Evaluate the interest of available areas for each subgroup;
3) Apply the adjusted winner procedure and allocate all available areas among two subgroups.
4) For each subgroup apply steps 1-3 if it contains several countries.

Modified Adjusted Winner Procedure

<table>
<tr><th>Step 0</th><th>Step 1</th><th>Step 2</th><th>Step 3</th><th>Step 4</th><th>Step 5</th></tr>
<tr><td rowspan="8">China,
Republic of Korea,
Iceland, Russia,
Japan, Denmark,
Norway, USA,
Canada</td><td rowspan="5">China,
Republic of
Korea,
Iceland,
Russia,
Japan,
Denmark</td><td rowspan="3">China,
Republic of
Korea,
Iceland,
Russia</td><td rowspan="3">China,
Republic of
Korea,
Iceland</td><td rowspan="2">China,
Republic of
Korea</td><td>China</td></tr>
<tr><td>Republic of
Korea</td></tr>
<tr><td colspan="2">Iceland</td></tr>
<tr><td colspan="3">Russia</td></tr>
<tr><td rowspan="2">Japan,
Denmark</td><td colspan="3">Japan</td></tr>
<tr><td colspan="3">Denmark</td></tr>
<tr><td rowspan="3">Norway,
USA,
Canada</td><td rowspan="2">Norway,
USA</td><td colspan="3">Norway</td></tr>
<tr><td colspan="3">USA</td></tr>
<tr><td>Canada</td><td colspan="3">Canada</td></tr>
</table>

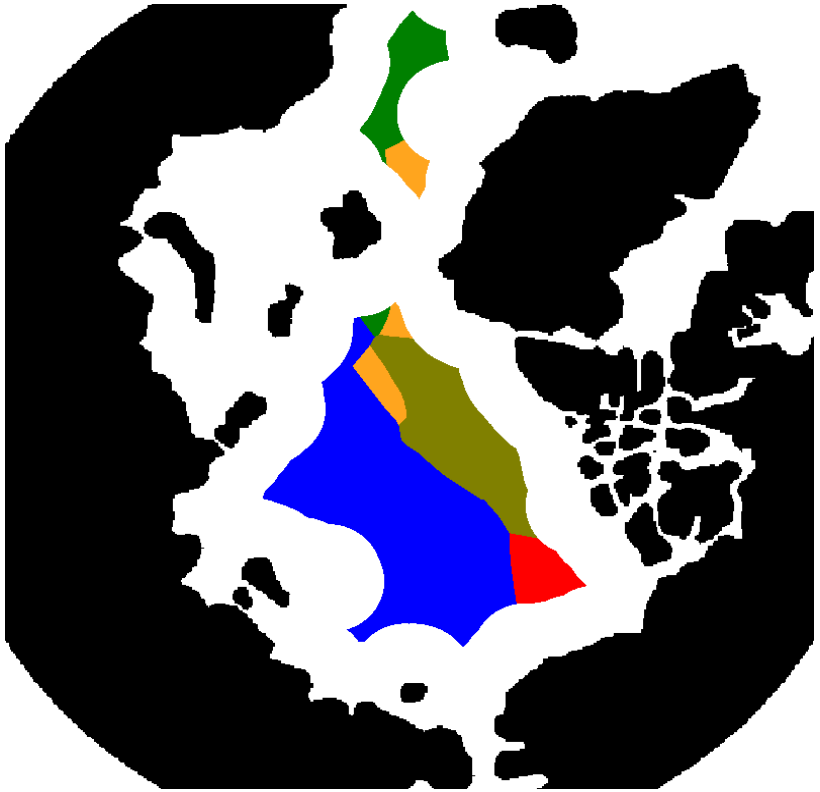
Modified Adjusted Winner Procedure

	USA		Denmark		China
	Russia		Norway		Japan
	Canada		Iceland		Republic of Korea
			Shared ownership		

Modified Adjusted Winner Procedure

Country	Scenario	
	Satisfaction level	Allocated areas
USA	-2589	2051
Russia	-2653	2298
Canada	-4882	1126
Denmark	-4479	1772
Norway	-2589	2034
Iceland	-2607	0
China	0	0
Japan	-791	0
South Korea	-10	0
TOTAL	-20601	9281

Shared allocation



Initial allocation

Final Allocation

	USA		Denmark		China
	Russia		Norway		Japan
	Canada		Iceland		Republic of Korea
			Shared ownership		

Number of shared areas

Countries	USA	Russia	Canada	Denmark	Norway	Iceland	China	Japan	South Korea
USA	-	0	1	351	1	0	0	0	0
Russia		-	0	385	0	0	0	0	0
Canada			-	911	0	0	0	0	0
Denmark				-	667	0	0	0	0
Norway					-	0	0	0	0
Iceland						-	0	0	0
China							-	0	0
Japan								-	0
South Korea									-

Shared allocation

Country	Total satisfaction
USA	-3494
Russia	-3493
Canada	-3494
Denmark	-3495
Norway	-3494
Iceland	-2607
China	0
Japan	-791
South Korea	-10
TOTAL	**-20877**

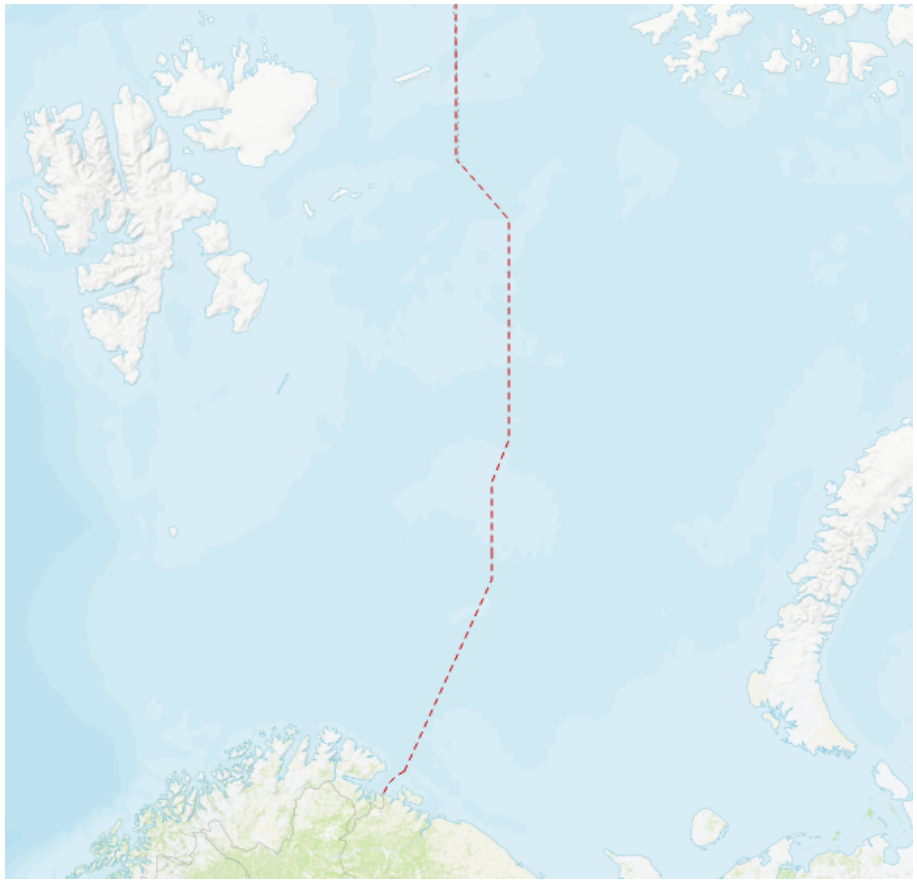
Conclusion

- A level of interest of all areas in Arctic for each country was evaluated;
- A novel model of disputable zones allocation in the Arctic was proposed;
- We strongly believe that early forecast of such potential disputable zones and discussions on different scenarios of resource allocation might ease the decision making process in international relations in Arctic region.

Thank you!

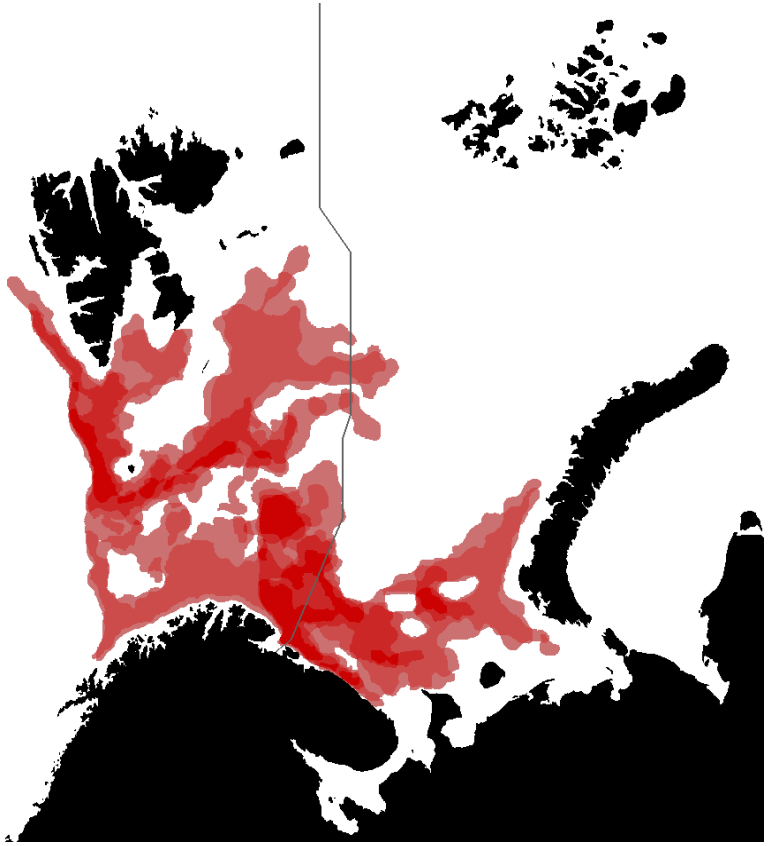
Other applications: Barents sea

- Current maritime borders



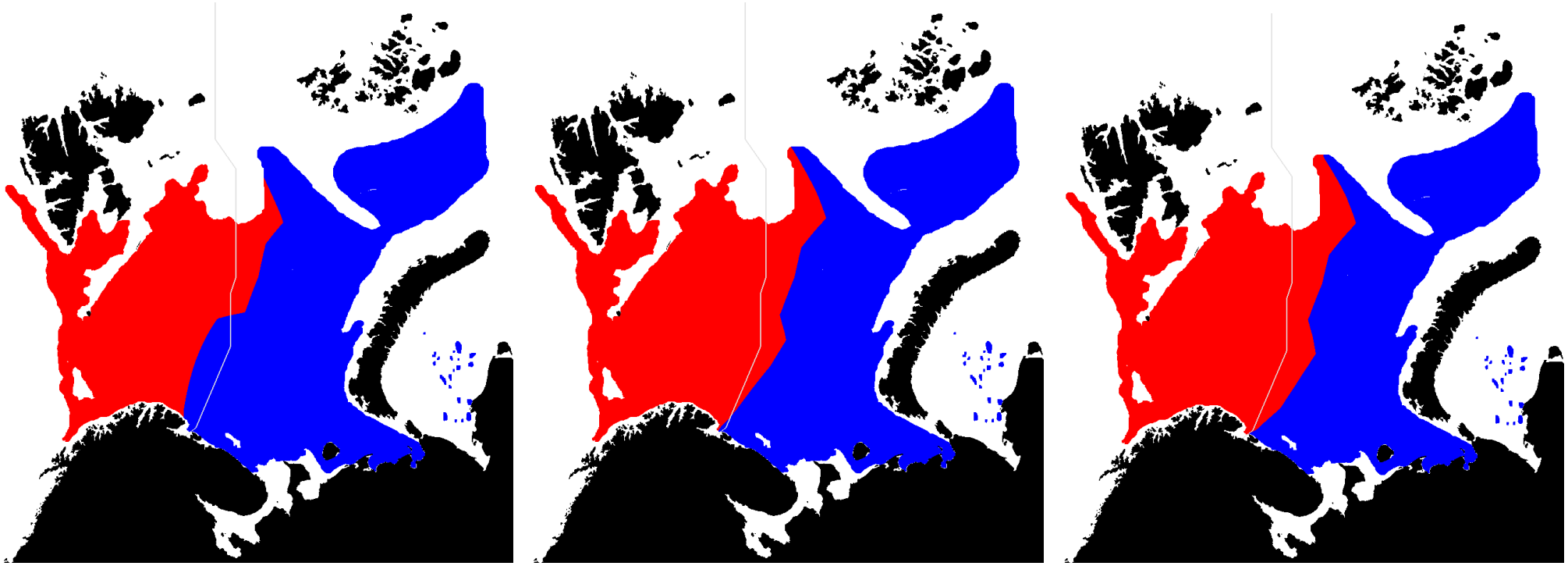
Resources in the Barents sea

Availability of oil and gas



Availability of fish

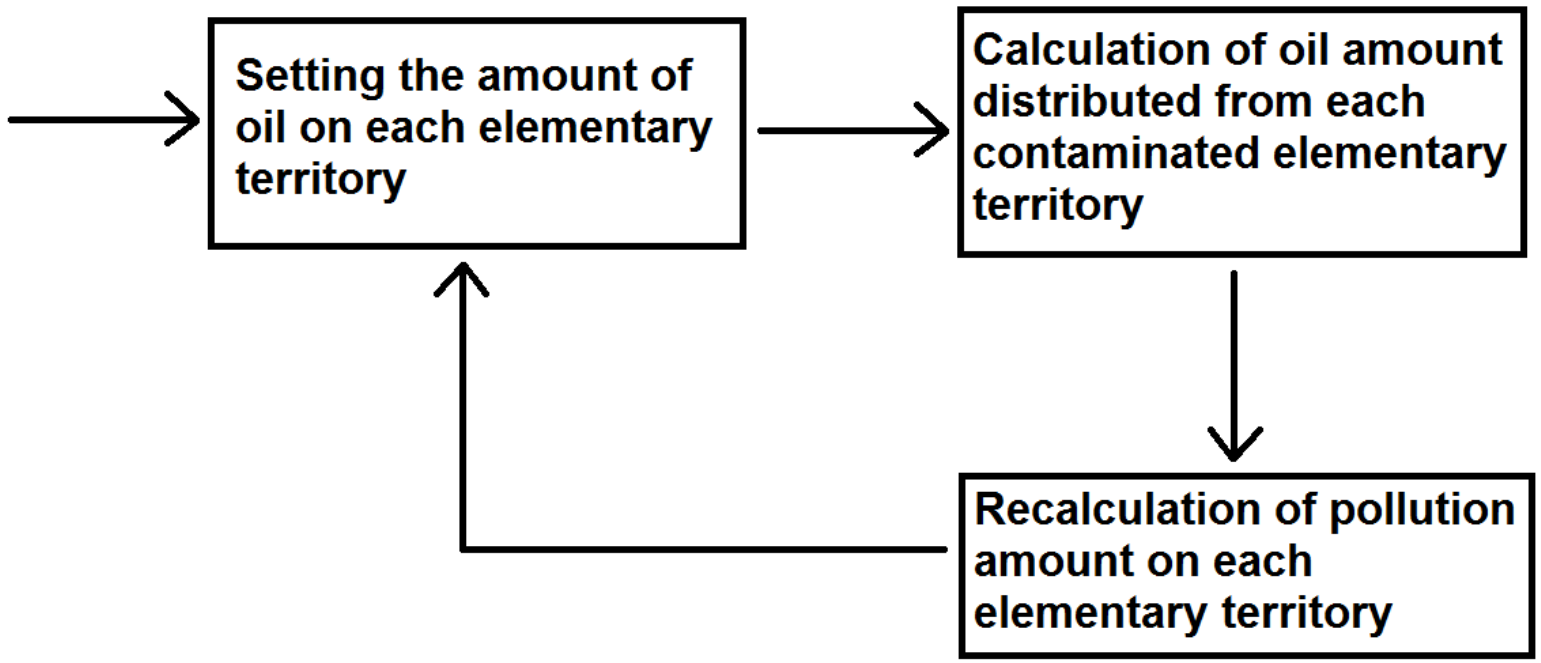
Barents sea: results



α=1 **α=5** **α=10**

α - relative importance of oil and gas.

Barents sea: potential oil spills analysis



Scheme of the simulation algorithm

Barents sea: potential oil spills analysis

Oil spills without strong flows

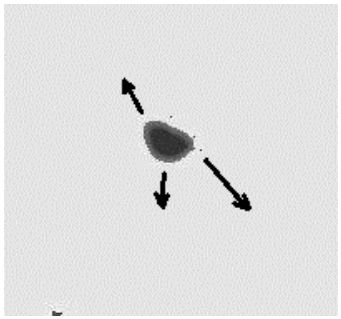
50 iterations

100 iterations

150 iterations

200 iterations

Oil spills with strong flows



500 iterations

Output in 2017

- 5 publications (5 - Web of Science и Scopus);
- 5 talks at international schools and conferences as the main speaker
- 12 talks at international schools and conferences as the co-author