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MARS PROJECT

Managing Aquatic ecosystems and water Resources under multiple Stress

# TERMINOLOGY

## — *STRESSOR – DRIVER – PRESSURE – STATE – IMPACT – RESPONSE* —

## — *CLASSIFYING SYNERGISTIC AND ANTAGONISTIC INTERACTION EFFECTS* —


## Contributors

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## Introduction

In order to foster the communication process and to harmonize the MARS approaches and outputs, the project requires agreement on a ***common terminology***. This contribution is designed as a 'living document', harmonizing the terminology by defining the term *Stressor* and the components of the DPSIR conceptual framework (EEA 1999), i.e. *Driver*, *Pressure*, *State*, *Impact* and *Response*.
To allow for a streamlined analysis of multistressor interactions, MARS adopts the systematic classification for defining synergistic and antagonistic effects of Piggott et al. (2015).

## Term: *STRESSOR*

1. A *Stressor* is any environmental change in a factor that exceeds the normal variation and causes some response[1] by the system of interest (Odum 1985, Underwood 1989, Kolasa & Pickett 1992, Piggott et al. 2015). The system of interest can be at any organizational level, e.g. organism, population, ecosystem.
2. A *Stressor* can be of natural or anthropogenic origin. The response caused by the *Stressor* can be beneficial or deleterious to the system of interest (Ban et al. 2014).
3. The term *Stressor* is not used in the terminology of the DPSIR framework. According to (1) a *Stressor* can belong to either the *Pressure* or *State* category[2]; the main thing is: it's the (putative) cause in a cause-and-effect chain.
4. *A direct stressor* represents the immediate cause of an effect (e.g. oxygen depletion causing suffocation of fish). If the stressor-effect on a species / biological community is studied, *direct stressors* affect the niche of the species / habitat template of the community.

[1] Not to be confused with the term *Response* within the DPSIR framework (see below).
[2] A *Stressor* belonging to the category of *Pressures* is always of anthropogenic origin. Factors belonging to the category of *Drivers* can be defined as *Indirect stressors* (see 4.).

*Indirect stressors* are preceding factors in a causal pathway conditioning an effect (e.g. flow variation [causing changes in near bottom flow] causing a response in invertebrate communities; Statzner & Bêche 2010). *Direct stressors* are often difficult to measure, thus empirical (field) studies mostly make use of *indirect stressors* as explanatory variables.

## Terms: *DRIVER – PRESSURE – STATE – IMPACT – RESPONSE*

Table 1: Definition of the DPSIR components (IMPRESS 2002, modified)

| Term | Definition |
|---|---|
| Driver | An anthropogenic activity (e.g. agriculture, industry) or climate change phenomenon (climate warming, changes in precipitation) that may have an environmental effect |
| Pressure | The direct effect of the driver (for example, an effect that causes a change in flow or a change in the water chemistry) |
| State | The condition of the system under study (e.g. water body) resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics) |
| Impact | Effects on human beings, ecosystems and man-made capital resulting from changes in environmental *State* with relevance for valued ecosystem phenomena (e.g. processes and/or components) actively or passively required, demanded, or used by man (e.g. ecosystem services), triggering social *Response.* |
| Response | The management or policy measures taken to improve the state of the water body (e.g. restricting abstraction, limiting point source discharges, developing best practice Guidance for agriculture) |

1. MARS follows the terminology defined by CIS Guidance IMPRESS (2002), except for the definition of the *Impact* category (Table 1).
2. MARS refers to the *Drivers* and *Pressures* specified in EC (2014) (Table 2 and Table 3). The main groups of *Pressures* comprise point and diffuse pressures, abstraction/flow diversion, physical alteration, dams and locks, and hydrological alteration.
3. Most response variables studied in MARS (e.g. biological conditions, functions, processes) fall into the *State* category (unless explicitly related to ecosystem services). Within the *State* category, we distinguish between abiotic and biotic *States*.
   The biological, hydromorphological, chemical and physico-chemical quality elements of the Water Framework Directive belong to the *State* category.
4. *Impact* is defined as effects on human beings, ecosystems and man-made capital resulting from changes in environmental *State* with relevance for valued ecosystem phenomena (e.g. processes and/or components) actively or passively required, demanded or used by man. The *Impact* (and not the *State*) triggers social *Response* (see Figure 1). Ecosystem services belong to the *Impact* category[3].

***Note:*** *Various frameworks for defining and categorizing pressure parameters exist (e.g. 'pressure groups' defined in the EFI+ project). These frameworks can be integrated into DPSIR concept as outlined in this document, mostly by re-evaluating the categories and reassigning them into the Pressure and State categories.*

[3] see *Additional notes on the Impact category* (page 9)

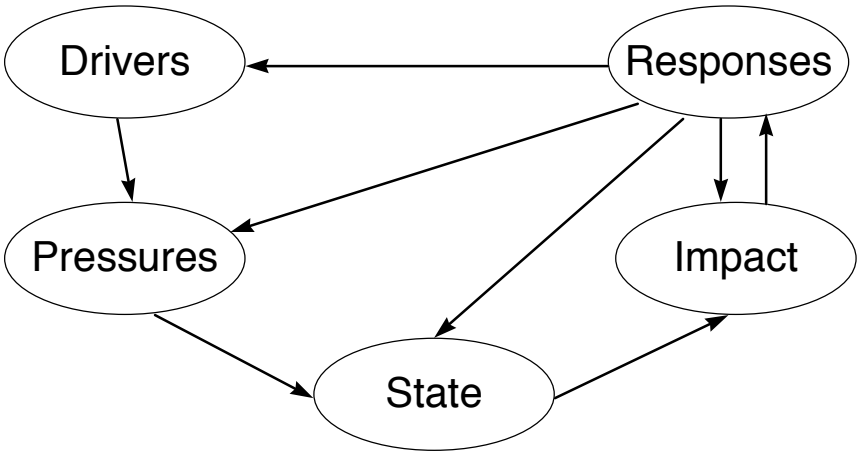


Figure 1: The DPSIR framework for reporting on environmental issues (EEA 1999)

## *Driver*

**Definition:**
An anthropogenic activity (e.g. agriculture, industry) or climate change phenomenon (climate warming, changes in precipitation) that may have an environmental effect.

Table 2: List of *Drivers* following EC (2014)

| Driver | Clarification |
|---|---|
| Agriculture | Includes all farming activities, agriculture and livestock land use and land cover change |
| Climate change phenomenon (Air temperature change, Evapotranspiration change, Precipitation change)* | |
| Energy – hydropower | |
| Energy – non-hydro | Including cooling activities for thermal and nuclear plants |
| Fisheries and aquaculture | Commercial fishing and aquaculture (not recreational or sports angling, included in category 'Recreation' below) |
| Flood protection/ Flood risk management | |
| Forestry | |
| Industry | All kinds of industry not included under other categories |
| Tourism and recreation | Includes bathing, leisure boating and sailing, sports fishing/angling. It does not include the urban development linked to tourism (under category 'Urban development'). |
| Transport | Road and rail traffic, shipping, aviation |
| Urban development | Includes urban development linked to household, non-manufacturing commercial activities, tourism. |

* added by MARS

## *Pressure*

**Definition:**
The direct effect of the driver (for example, an effect that causes a change in flow or a change in the water chemistry).

Table 3: List of Pressures according to EC (2014)
*Note that the Pressures are defined in connection to the main Driver(s)*

| Pressure | Main Driver(s) | Clarification on pressures |
|---|---|---|
| ***1. Point pressure*** | | |
| 1.1 Point – Urban waste water GW | Urban development | Included or not in the UWWT Directive. Includes discharges from non-manufacturing commercial areas which can largely be assimilated to urban waste water. Includes discharges of raw or partially treated urban waste water which are identified as point sources. |
| 1.2 Point - Storm Overflows GW | Urban development | Overflows from separated or combined sewers identified as point sources (for diffuse see 'Diffuse – Urban run-off' below). |
| 1.3 Point – IED plants # | Industry | Industrial point sources from plants included in the E-PRTR$. |
| 1.4 Point – Non IED plants # | Industry | Any industrial point sources not included in the E-PRTR$. |
| 1.5 Point - Contaminated Sites/Abandoned industrial sites GW | Industry | Pollution resulting from an abandoned industrial site or a site contaminated due to past industrial activities, illegal dumping of industrial waste or a pollution accident and which is identified as point source (for diffuse see below 'Diffuse – Contaminated sites/abandoned industrial sites). This category does not cover existing industrial activities. |
| 1.6 Point - Waste disposal sites GW | Urban development | Point sources due to urban or industrial waste disposal sites. |
| 1.7 Point - Mine waters GW | Industry | Point sources due to the collection of water in an open pit or underground mine which has to be brought to the surface in order to enable the mine to continue working. It does not include waste water from the industrial processes. |
| 1.8 Point - Aquaculture | Aquaculture | |
| 1.9 Point – Other | *Not specified* | Other point sources not included in the categories above. |
| ***2. Diffuse pressure*** | | |
| 2.1 Diffuse – Urban run off GW | Urban development, Industry | Storm overflows and discharges in urbanized areas not identified as point sources |
| 2.2 Diffuse – Agricultural GW | Agriculture | Pesticides and nutrients from arable land and manure |
| 2.3 Diffuse – Forestry | Forestry | |
| 2.4 Diffuse – Transport | Transport | Diffuse pollution from road and train traffic, aviation and infrastructure. |
| 2.5 Diffuse – Contaminated sites/Abandoned industrial sites GW | Industry | Pollution resulting from an abandoned industrial site or a site contaminated due to past industrial activities, illegal dumping of industrial waste or a pollution accident and which is identified as diffuse source (for point see above 'Point – Contaminated sites/abandoned industrial sites). This category does not cover existing industrial activities. |
| 2.6 Diffuse – Discharges not connected to sewerage network | Urban development | Pollution resulting from urban waste water not connected to sewers and identified as a diffuse source. |
| 2.7 Diffuse – Atmospheric deposition | Agriculture, Energy non-hydro, Industry, Transport, Urban development | Diffuse pollution from atmospheric deposition from any origin |

| Pressure | Main Driver(s) | Clarification on pressures |
|---|---|---|
| 2.8 Diffuse – Mining | Industry | Pollution from mining activities which are identified as diffuse (for point sources see categories above ) |
| 2.9 Diffuse – Aquaculture | Aquaculture | |
| 2.10 Diffuse – other | *Not specified* | Other diffuse sources not included in the categories above. |
| ***3. Abstraction/flow diversion of surface waters*** | | |
| 3.1 Abstraction/Flow Diversion – Agriculture GW | Agriculture | Includes water transfers and abstractions for irrigation and livestock breeding. |
| 3.2 Abstraction/Flow Diversion – Public Water Supply GW | Urban development | Includes water transfers. Affection to transitional and/or coastal waters possible only in case of desalination plants. |
| 3.3 Abstraction/Flow Diversion – Industry | Industry | Abstraction for industrial processes (cooling water is covered under the category 'Abstraction – cooling water') |
| 3.4 Abstraction/Flow Diversion – Cooling water | Industry, Energy non-hydro | |
| 3.5 Abstraction/Flow Diversion - Fish farms | Aquaculture | Typically off-line fish farms |
| 3.6 Abstraction/Flow Diversion – other | *Not specified* | Abstraction for any other purpose not listed above. |
| ***4. Physical and hydrological alteration*** | | |
| 4.1.1 Physical alteration of channel/bed/riparian area/shore of water body for flood protection | Flood protection | Refers largely to longitudinal alterations to water bodies. |
| 4.1.2 Physical alteration of channel/bed/riparian area/shore of water body for agriculture | Agriculture | Refers largely to longitudinal alterations to water bodies. Includes land drainage to enable agriculture activities. |
| 4.1.3 Physical alteration of channel/bed/riparian area/shore of water body for navigation | Transport | Refers largely to longitudinal alterations to water bodies. |
| 4.1.4 Physical alteration of channel/bed/riparian area/shore – other | *Not specified* | Refers largely to longitudinal alterations to water bodies. |
| 4.1.5 Physical alteration of channel/bed/riparian area/shore – unknown or obsolete | *Not specified* | In case the driver for the physical modification is unknown. |
| 4.2.1 Dams, barriers and locks for hydropower | Energy – hydropower | |
| 4.2.2 Dams, barriers and locks for flood protection | Flood Protection | |
| 4.2.3 Dams, barriers and locks for drinking water | Urban development | |
| 4.2.4 Dams, barriers and locks for irrigation | Agriculture | |
| 4.2.5 Dams, barriers and locks for recreation | Recreation | Small dams are used in rivers to create recreational areas (bathing waters) and also angling areas |
| 4.2.6 Dams, barriers and locks for industry | Industry, Energy non-hydro | Dams are sometimes created to provide freshwater for large industry e.g. typically for cooling purposes |
| 4.2.7 Dams, barriers and locks for navigation | Transport | |
| 4.2.8 Dams, barriers and locks – other | *Not specified* | |
| 4.2.9 Dams, barriers and locks – unknown or obsolete | *Not specified* | |

| Pressure | Main Driver(s) | Clarification on pressures |
|---|---|---|
| 4.3.1 Hydrological alteration – agriculture | Agriculture | A change in the flow and water level regime (e.g. due to land drainage) including dry river beds or lakes falling dry |
| 4.3.2 Hydrological alteration – transport | Transport | A change in the flow and water level regime - typically due to inland navigation including dry river beds or lakes falling dry |
| 4.3.3 Hydrological alteration – hydropower | Energy – hydropower | A change in the flow and water level regime (e.g. hydropeaking) including dry river beds or lakes falling dry |
| 4.3.4 Hydrological alteration – public water supply | Urban development | A change in the flow and water level regime including dry river beds or lakes falling dry |
| 4.3.5 Hydrological alteration – aquaculture | Fisheries and aquaculture | A change in the flow and water level regime including dry river beds or lakes falling dry |
| 4.3.6 Hydrological alteration – climate change* | Climate change | Change of mean or extreme values beyond long-term natural variability range |
| 4.3.7 Hydrological alteration – other | *Not specified* | |
| 4.4 Other hydromorphological alterations | *Not specified* | Other hydromorphological alterations not included in any of the categories above, including alteration of water level or volume for purposes not identified above. |
| ***5. Other pressures*** | | |
| 5.1 Introduced species and diseases | Transport, Fisheries and aquaculture, Tourism and recreation | Includes invasive alien species. |
| 5.2 Exploitation of/removal of animals/plants | Recreation, Fisheries and aquaculture | Commercial fishing or recreational/sports angling, commercial harvesting of plants or algae from water bodies. |
| 5.3 Litter/fly-tipping | Urban development, Transport | Includes illegal waste deposits, litter from ships, etc. (All waste from land area) |
| 5.4 Change in thermal, mixing or ice regime* | Climate change | Change of mean or extreme values beyond long-term natural variability range |
| ***6. Groundwater pressure (only relevant for groundwater bodies**)*** | | |
| 6.1.1 Groundwater recharges – agriculture | Agriculture | Change in long-term average (trend), seasonal or extreme event return periods leading to change in groundwater resource availability (groundwater level and yield decline and groundwater drought), reduced base-flow to surface waters and groundwater-dependent wetlands and potentially changes in groundwater qualitative status due to reduction in dilution. Increased recharge may be associated with anomalously high groundwater levels and may be associated with groundwater flooding, sewer discharges and linked surface water quality issues. |
| 6.1.2 Groundwater recharges – energy – non-hydro | Energy – non-hydro | |
| 6.1.3 Groundwater recharges – industry | Industry | |
| 6.1.4 Groundwater recharges – urban development | Urban development | |
| 6.1.5 Groundwater recharges – climate change | Climate change | |
| 6.2 Groundwater – alteration of water level or volume | Industry, Urban development | This category includes activities to alter the level of groundwater in order to carry out an underground activity (typically mining or large civil works). This does not include the alteration of the water level due to current or past overexploitation of the groundwater resources (this case is captured under the categories 'Abstraction' below). |
| 6.3.1 Groundwater abstractions for agriculture* | Agriculture | |
| 6.3.2 Groundwater abstractions for urban development (drinking water)* | Urban development | |
| 6.3.3. Groundwater abstractions for industry* | Industry | |

| Pressure | Main Driver(s) | Clarification on pressures |
|---|---|---|
| 6.3.4 Groundwater abstractions for other purposes* | *Not specified* | |
| 6.4.1 Groundwater drainage – agriculture* | Agriculture | |
| 6.4.2 Groundwater drainage – urban development* | Urban development | |
| 6.4.3 Groundwater drainage for other purposes* | *Not specified* | |

GW *Pressures* also relevant for groundwater bodies

# Directive on Industrial Emissions, committing European Union member states to control and reduce the impact of industrial emissions on the environment.

$ European Pollutant Release and Transfer Register

* added by MARS

** In studies of surface waters, these *Pressures* are considered as *Drivers* affecting surface water *Pressures* such as *4.3.1 Hydrological alteration – agriculture*.

## *State*

**Definition:**
The condition of the system under study (e.g. water body) resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics).

Table 4: Exemplary list of *State* indicators
This table lists the various 'quality elements' used to classify the ecological status according to the European Water Framework Directive

| Category | Quality element | State indicator (example) |
|---|---|---|
| Biological | Phytoplankton | Composition, abundance and biomass of phytoplankton |
| | Macrophytes and phytobenthos | Composition and abundance of macrophytes and phytobenthos |
| | Benthic invertebrates | Composition and abundance of benthic invertebrate fauna |
| | Fish fauna | Composition, abundance and age structure of fish fauna |
| Hydro-morphological | Continuity | Presence of transversal migration barriers |
| | | Lateral connectivity to floodplain water bodies |
| | Hydrology | Quantity and dynamics of water flow |
| | | Connection to groundwater bodies |
| | | Water residence time |
| | Morphology | Depth and width variation |
| | | Structure and substrate of the water body bed |
| | | Structure of the water body shoreline |
| | Tidal regime | Freshwater flow |
| | | Wave exposure |
| Physico-chemical | General | Transparency |
| | | Thermal conditions |
| | | Oxygenation conditions |
| | | Salinity |
| | | Nutrient conditions |
| | | Acidification status |
| | Priority hazardous substances | Pollution by all priority substances identified as being discharged into the body of water |
| | Other pollutants | Pollution by other substances identified as being discharged in significant quantities into the body of water (River Basin Specific Pollutants) |

## *Impact*

**Definition:**
Effects on human beings, ecosystems and man-made capital resulting from changes in environmental *State* with relevance for valued ecosystem phenomena (e.g. processes and/or components) actively or passively required, demanded or used by man (e.g. ecosystem services), triggering social *Response*.

*… to be completed …*

# Additional notes on the *Impact* category

According to IMPRESS (2002), the distinction made between *State* and *Impact* "separates effects that are sometimes combined, or confused". EEA (2012) defines *Impacts* as effects on human beings, ecosystems and man-made capital resulting from changes in environmental *State*. This definition includes both ecosystem and human welfare effects, obscuring the boundary between *State* and *Impact* (Cooper 2013). EEA (1999) describes that changes in environmental *State* cause *Impacts* on the social and economic functions on the environment, such as the provision of adequate conditions for health, resources availability and biodiversity. The ecological water body status, for instance, expressed as one of five classes, *rates* the environmental state and thus represents an *Impact* variable[4]. According to this definition, only the *Impact* (and not the *State*) triggers societal *Response* (see Figure 1).

Recent literature merging the DPSIR framework with the ecosystem service cascade (e.g. Müller & Burkhard 2012) places the ecosystem services (i.e. ecosystem processes and/or components actively or passively required, demanded or used by man; Jax et al. 2013) into the *Impact* component. According to EC (2014) concepts such as 'nutrient pollution', 'acidification' or 'elevated temperatures' are defined as *Impacts*. These concepts can be regarded as effects on ecosystems with relevance for required processes and components, triggering social *Response*.

[4] Here, the quantification of ecological status (using metrics to measure, for instance, the composition, abundance and biomass of phytoplankton) needs to be distinguished from the classification of ecological status (i.e. subdividing the measured status gradient into concrete classes of high, good, moderate, poor and bad status).

## CLASSIFYING SYNERGISTIC AND ANTAGONISTIC INTERACTION EFFECTS

1. Synergism and antagonism is defined relative to individual stressor effects in absolute terms, following Piggott et al. (2015).
2. The classification system is based on an additive effects model that combines the magnitude and response direction (+ or -) of the cumulative effect (i.e. effect of combined stressors relative to control) and interaction effect (i.e. effect deviation from the additive model prediction) (Figure 2).
3. In this directional classification system, the meanings of the words synergism and antagonism respectively translate to “more-than” or “less-than” predicted additively in absolute terms (i.e., with the stated direction).
4. An additive effect (i.e., no significant interaction in ANOVA) represents the sum of the individual effects that may arise from double-positive effects (e.g., +1 + 1 = 2 for an effect of one for each stressor), double-negative effects (-1 + -1 = -2), or opposing effects (-1 + 1 = 0).
5. An interaction that deviates from additive (i.e., a significant two-factor interaction term in ANOVA) and is less than the sum of the individual effects or less-than- or-equal-to any individual effect in the same direction is positive antagonistic (+A; less positive than predicted additively) when $+1+1=0<(+A)<2$ or $-1+1 = -1 \leq (+A) < 0$, or negative antagonistic (-A; less negative than predicted additively) when $-1 + -1 = -2 < (-A)<0$ or $-1 + 1 = 0 < (-A) \leq 1$.
6. A deviation from additive that is greater than the sum of individual effects and greater than any individual effect in the same direction or has an interaction effect that is greater than both in absolute terms is positive synergistic (+S; more positive than predicted additively) when $+1+1=(+S)>2$ or $-1+-1=(+S)>0$ or $-1 + 1 = (+S) > 1$, or negative synergistic (-S; more negative than predicted additively) when $+1 + 1 = (-S)<0$ or $-1+ -1=(-S)<-2$ or $-1+1 = (-S) < -1$.
7. All potential interaction types and directional classifications for two-stressor combinations are given in Table 5.

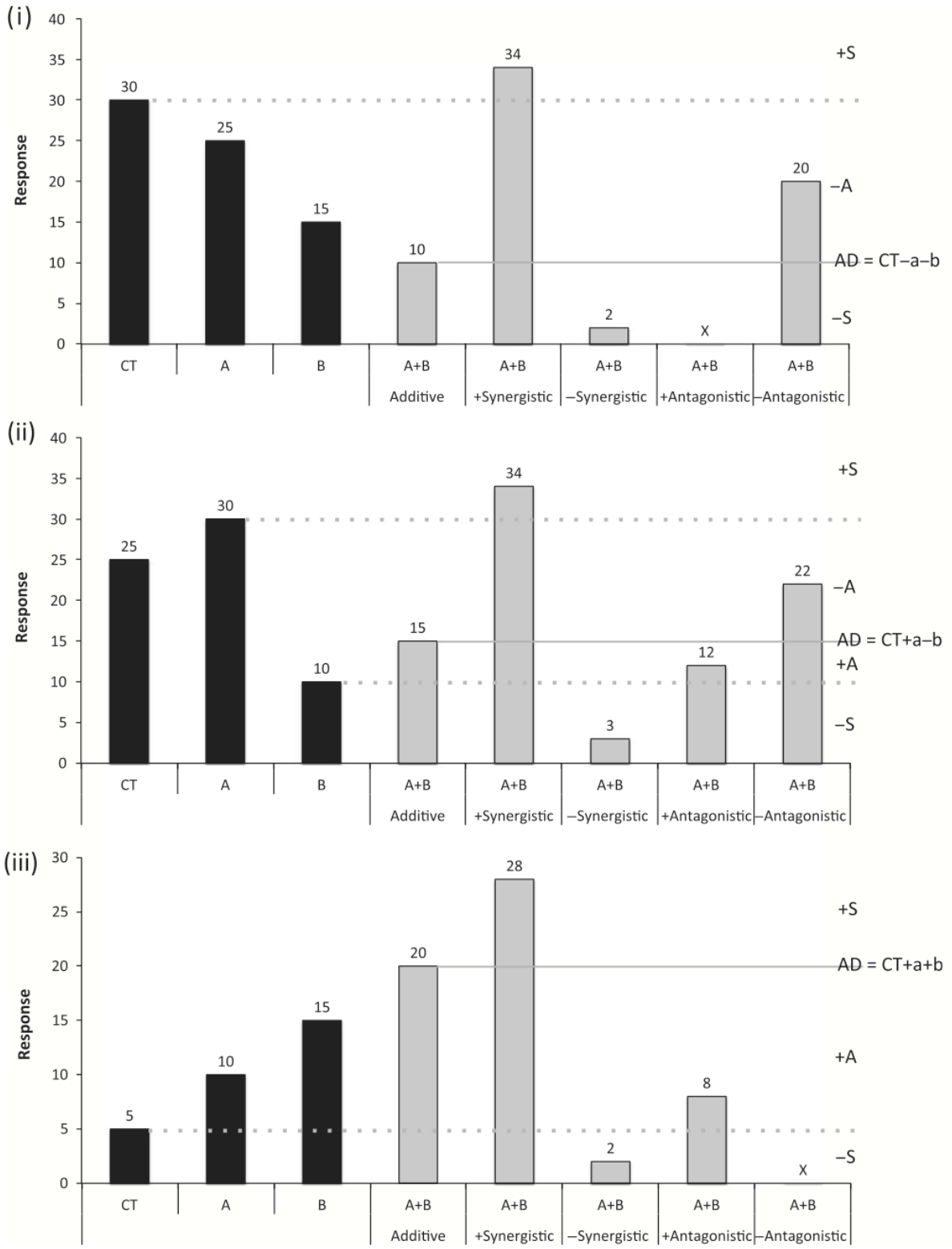


Figure 2: Interaction types from data presented in factorial studies determined from the magnitude and direction of the cumulative effect and interaction effect in absolute terms. Treatments in factorial studies include control (CT), with stressor A (A), with stressor B (B), and with both stressors (A + B). Directional interaction classes are additive (AD), +synergistic (+S), -synergistic (-S), +antagonistic (+A) and -antagonistic (-A) that vary depending on A + B compared to the additive sum (AD) of individual effects for stressor A (a), B (b) relative to the control (CT). The three plots show interaction types that have double-negative (i), opposing (ii), and double-positive (iii) individual stressors effects on the response variable of interest. (X) indicates that an interaction class is not applicable for the interaction type in question. Figure taken from Piggott et al. (2015).

Table 5: Potential interaction types and directional classifications for two-stressor combinations. The direction of individual stressor effects (a) or (b) and interaction effect (a + b) are coded as positive (+), negative (-), or neutral (0). Double-sign symbols (++) or (--) indicate the direction of a cumulative effect (a + b) that is greater than the sum of individual effects and greater than any individual effect in the same direction or has an interaction effect that is greater than both in absolute terms. Directional interaction classes are additive (AD), +synergistic (+S), -synergistic (-S), +antagonistic (+A), and -antagonistic (-A).

| Interaction Type | a | b | a + b | Classification |
|---|---|---|---|---|
| Double positive | + | + | ++ | +S |
| | + | + | + | +S |
| | + | + | 0 | AD |
| | + | + | – | +A |
| | + | + | –– | –S |
| Double negative | – | – | ++ | +S |
| | – | – | + | –A |
| | – | – | 0 | AD |
| | – | – | – | –S |
| | – | – | –– | –S |
| Opposing | + | – | ++ | +S |
| | + | – | + | –A |
| | + | – | 0 | AD |
| | + | – | – | +A |
| | + | – | – | –S |
| Opposing | – | + | ++ | +S |
| | – | + | + | –A |
| | – | + | 0 | AD |
| | – | + | – | +A |
| | – | + | –– | –S |
| Negative Neutral | – | 0 | ++ | +S |
| | – | 0 | + | –A |
| | – | 0 | 0 | AD |
| | – | 0 | – | –S |
| | – | 0 | –– | –S |
| Negative Neutral | 0 | – | ++ | +S |
| | 0 | – | + | –A |
| | 0 | – | 0 | AD |
| | 0 | – | – | –S |
| | 0 | – | –– | –S |
| Positive Neutral | + | 0 | ++ | +S |
| | + | 0 | + | +S |
| | + | 0 | 0 | AD |
| | + | 0 | – | +A |
| | + | 0 | –– | –S |
| Positive Neutral | 0 | + | ++ | +S |
| | 0 | + | + | +S |
| | 0 | + | 0 | AD |
| | 0 | + | – | +A |
| | 0 | + | –– | –S |
| Double Neutral | 0 | 0 | ++ | +S |
| | 0 | 0 | + | +S |
| | 0 | 0 | 0 | AD |
| | 0 | 0 | – | –S |
| | 0 | 0 | –– | –S |

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