**Appendix 1: Studies included in meta-analysis**

**Ecological Monographs**

**Roethler, M., Fales, R., Donoghue, C., and Padilla-Gamiño, J.**

**Impacts of climate change (ocean warming and acidification) on kelps: a meta-analysis**

Table S1. Summary of data pulled from each study.

| **Study** | **Stress-or** | **Species** | **Location** | **Ecoregion** | **Province** | **Realm** | **Life stage** | **Response category** | **Response variable** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Andersen et al. 2013 | Warming | *Saccharina*  *latissima* | Norway (Bergen /  Grimstad / Drøbak) | Southern  Norway / North Sea | Northern  European Seas | Temperate Northern  Atlantic | Young sporophyte | Net  primary productivity | NPmax |
| Fluorescence | α, Ek, Fv/Fm, NPQ, Ec |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c* : Chlorophyll-*a*  ratio,  Fx : Chlorophyll-*a* ratio, V+Z : Chlorophyll-*a*  ratio |
| Respiration | RD |
| Augyte et al. 2019 | Warming | *Saccharina*  *agustisima* | USA (Maine, Casco Bay, Harps-well,  Bailey  Island) | Gulf of Maine/  Bay of Fundy | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Gametophyte | Growth | Number of cells |
| Length |
| Young sporophyte |
| Bartsch et al. 2013 | Warming | *Laminaria digitata* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Reproduction | Sorus induction,  Total  fertile area,  Reproductive area  allocation, Half  maximal reaction time |
| Spore/ germling | Germination rate, Spore  production |
| Bi et al. 2021 | Acidification | *Saccharina*  *japonica* | China (Shanghai) | East China Sea | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Gametophyte | Enzyme activity | Total CA, CAext, CAint |
| Biskup et al. 2014 | Warming | *Laminaria ochrol-euca* | Portugal | South  European  Atlantic Shelf | Lusitanian | Temperate Northern  Atlantic | Young sporophyte | Net  primary productivity | GPmax |
| Respiration | RD |
| Bollen et al. 2016 | Warming | *Undaria pinnatifida,*  *Ecklonia radiata, Lessonia variegata* | New  Zealand  (Tauranga Harbour) | Northeastern New Zealand | Northern New  Zealand | Temperate  Australasia | Adult  sporophyte | Stress  response | Antioxidant pool size |
| Fluorescence | ETRmax, Fv/Fm |
| Pigments | Chlorophyll-*a*, VAZ : Chlorophyll-*a*  ratio |
| Bolton &  Anderson 1987 | Warming | *Ecklonia biruncinata* | South  Africa (Glengariff) | Natal | Agulhas | Temperate Southern  Africa | Gametophyte | Growth | Length |
| *Ecklonia maxima* | South  Africa (Kommetjie) | Namaqua | Benguela |
| Reproduction | Number of  oogonia |
| Bolton & Levitt 1985 | Warming | *Ecklonia maxima* | South  Africa (Cape  Peninsula) | Namaqua | Benguela | Temperate Southern  Africa | Gametophyte | Growth | Length |
| Bolton & Lüning 1982 | Warming | *Saccharina*  *latissima* | Norway (Espegrend) | Southern  Norway | Northern  European Seas | Temperate Northern  Atlantic | Young sporophyte | Growth | Elongation rate |
| United Kingdom (Isle of Man, Port Erin) | Celtic Seas |
| France (Brittany, Brest) |
| Germany (Helgoland) | North Sea |
| *Laminaria hyperborea* |
| *Laminaria digitata* | Canada (Nova Scotia, St. Margerets Bay | Scotian Shelf | Cold  Temperate Northwest  Atlantic |
| *Saccharina*  *latissima* |
| Canada (North West  Territories,  Igloolik) | Hudson Complex | Arctic | Arctic |
| Borlongan et al. 2018 | Warming | *Costaria costata* | Japan (Hokkaido  Island, Muroran City) | Northeastern  Honshu | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult sporophyte, gametophyte | Net  primary productivity | NP |
| Fluorescence | Fv/Fm |
| Respiration | RD |
| Borlongan et al. 2019a | Warming | *Alaria crassifolia* | Japan (Hokkaido  Island, Muroran City) | Northeastern  Honshu | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult sporophyte, gametophyte | Net  primary productivity | NP |
| Fluorescence | Fv/Fm |
| Respiration | RD |
| Borlongan et al. 2019b | Warming | *Saccharina*  *angustata* | Japan (Hokkaido  Island, Muroran City) | Northeastern  Honshu | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Net  primary productivity | NP |
| Fluorescence | Fv/Fm |
| Respiration | RD |
| Borlongan et al. 2020 | Warming | *Saccharina*  *japonica* | Japan (Hokkaido  Island, Muroran City) | Northeastern  Honshu | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult sporophyte, gametophyte | Net  primary productivity | NP |
| Fluorescence | Fv/Fm |
| Respiration | RD |
| Britton et al. 2016 | Acidification | *Ecklonia radiata* | Australia (Tasmania,  Fortescue Bay) | Bassian | Southeast Australian Shelf | Temperate  Australasia | Young sporophyte | Biochemical composition | RNA : DNA  ratio, RNA, DNA, δ13 C, C:N  ratio |
| Fluorescence | Fv/Fm, rETRmax |
| Growth | Weight change |
| Net  primary productivity | NP |
| Brown et al. 2014 | Warming, Acidification,  Multiple stressors | *Macrocystis*  *pyrifera* | USA (California, San Diego, Point Loma) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Biochemical composition | C:N  ratio |
| Fluorescence | α |
| Growth | Weight |
| Net  primary productivity | NPmax |
| Burdett et al. 2019 | Warming | *Laminaria hyperborea* | United Kingdom (Plymouth Sound) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Net  primary productivity | NP |
| *Laminaria digitata* |
| Fluorescence | Fv/Fm, Ek, α, rETRmax |
| Buschmann et al. 2004 | Warming | *Macrocystis*  *pyrifera* | Chile | Central Chile, Araucanian | Warm Temperate Southeastern Pacific | Temperate South America | Spore/ germling | Reproduction | Spore production, germination rate |
| Young sporophyte | Growth | Elongation rate |
| Choi et al. 2019 | Warming | *Eisenia*  *bicyclis* | Korea (Gyubuk, Ulleungdo, Dokdo) | Sea of  Japan/ East Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Gametophyte | Growth | Elongation rate |
| *Ecklonia cava* | Korea (Cheonan,  Shinan, Jangsan) | East China Sea | Warm Temperate Northwest  Pacific |
| Chu et al. 2019 | Acidification | *Saccharina*  *japonica* | China (Shandong, Rongcheng) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Biochemical composition | Soluble carbohydrates, proteins |
| Growth | Weight change |
| Net  primary productivity | NP |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c* |
| Chu et al. 2020 | Acidification | *Saccharina*  *japonica* | China (Shandong, Rongcheng) | Yellow Sea | Cold Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Biochemical composition | C:N  ratio,  Carbon, Nitrogen |
| Growth | Weight change |
| Net  primary productivity | NP |
| Respiration | RD |
| Cornwall et al. 2012 | Acidification | *Undaria pinnatifida* | New  Zealand (South  Island, Otago Harbour) | South New Zealand | Southern New  Zealand | Temperate  Australasia | Young sporophyte | Net  primary productivity | NP |
| Cruces et al. 2013 | Warming | *Lessonia nigrescens* | Chile (Valdivia, Playa  Rosada) | Araucanian | Warm Temperate Southeastern Pacific | Temperate South America | Young sporophyte | Fluorescence | Fv/Fm, ETRmax |
| Stress  response | Phlorotannin  content, Malondialdehyde, Radical scavenging  activity, Insoluble  phlorotannin content |
| Davison 1987 | Warming | *Saccharina*  *latissima* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Young sporophyte | Net  primary productivity | NPmax |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c*, Fx, Beta-carotene |
| Davison & Davison 1987 | Warming | *Saccharina*  *latissima* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Young sporophyte | Biochemical composition | Proteins, Amino-  nitrogen content, NO3-  nitrogen, Nitrogen, Laminarin, Mannitol |
| Enzyme activity | RuBisCO, GADPH, GAPDH, NR,  Glutamine  synthetase, Phosphoenolpyr-uvate  carboxykinase, MDH,  l-aspartate,  M-1-PDH |
| Growth | Weight change |
| Net  primary productivity | NPmax |
| Delebe-cq et al. 2016 | Warming | *Laminaria digitata* | France (Roscoff) | South  European  Atlantic Shelf | Lusitanian | Temperate Northern  Atlantic | Gametophyte | Fluorescence | α, rETRmax, Ek, NPQ |
| France (Wissant) | North Sea | Northern  European Seas |
| Diehl et al. 2020 | Warming | *Laminaria solidungula* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Young sporophyte | Biochemical composition | Carbon, Nitrogen, Mannitol, C:N ratio |
| Fluorescence | Fv/Fm |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c*, Fx, VAZ, DPS, Beta-carotene |
| Stress response | Phlorotannin content |
| Donham et al. 2021 | Acidification | *Macrocystis*  *pyrifera* | USA (California, San Diego, Mia’s Reef) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Young sporophyte | Survival | Density |
| Endo et al. 2017 | Warming | *Eisenia*  *bicyclis* | Japan (Oshika Peninsula) | Sea of  Japan/ East Sea | Cold  Temperate Northern  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Carbon, Nitrogen |
| Growth | Weight change, Elongation rate, Area change |
| Stress response | Phlorotannin content |
| Endo et al. 2021 | Warming | *Undaria pinnatifida* | Japan (Shizugawa Bay) | Northeastern  Honshu | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Growth | Weight change |
| Fain & Murray 1982 | Warming | *Macrocystis*  *pyrifera* | USA (California,  Laguna Beach) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Gametophyte, Young sporophyte | Net  primary productivity | NPmax |
| Respiration | RD |
| Falkenberg et al. 2013 | Acidification | *Ecklonia radiata* | Australia (Adelaide, Outer  Harbor) | Southern  Australian Gulfs | Southwest Australian Shelf | Temperate  Australasia | Adult  sporophyte | Biochemical composition | C:N ratio,  Carbon, Nitrogen |
| Growth | Weight change |
| Fernández et al. 2017 | Acidification | *Macrocystis*  *pyrifera* | New Zealand (Otago Harbour, Aramoana Beach) | South New Zealand | Southern New  Zealand | Temperate  Australasia | Adult  sporophyte | Net  primary productivity | pH change, NO3-  uptake, HCO3-  uptake, CO2  uptake, Total  alkalinity |
| Fernández et al. 2021 | Warming, Acidification,  Multiple stressors | *Macrocystis*  *pyrifera* | Chile (El Tabo / Las Docas) | Araucanian | Warm Temperate Southeastern Pacific | Temperate South America | Young sporophyte | Biochemical composition | C:N ratio,  Nitrogen, Carbon |
| Enzyme activity | NR,  Total CA |
| Fluorescence | α, rETRmax, Ek, Fv/Fm |
| Growth | Weight change |
| Net  primary productivity | NPmax |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c*, Fx |
| Fonck et al. 1998 | Warming | *Lessonia nigrescens* | Chile (Coquimbo) | Central Chile | Warm Temperate Southeastern Pacific | Temperate South America | Spore/ germling | Reproduction | Spore  production |
| *Lessonia trabeculata* |
| Fortes & Lüning 1980 | Warming | *Saccharina*  *latissima* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Growth | Elongation rate |
| Franco et al. 2017 | Warming | *Laminaria ochrole-uca* | Portugal (São Bartolomeu, Amorosa and Viana do Castelo) | South European  Atlantic Shelf | Lusitanian | Temperate Northern  Atlantic | Young sporophyte | Biochemical composition | Nitrogen |
| Growth | Weight change |
| Survival | Survival |
| Franke et al. 2021 | Warming | *Laminaria digitata, Hedophyllum nigripes* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Gametophyte | Reproduction | Sex ratio |
| Survival | Density |
| Young sporophyte | Biochemical composition | C:N ratio,  Carbon, Nitrogen |
| Fluorescence | Fv/Fm |
| Growth | Area change |
| Fredersdorf et al. 2009 | Warming | *Alaria*  *esculenta* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Spore/ germling | Reproduction | Germination rate |
| Adult  sporophyte | Fluorescence | Fv/Fm |
| Fu et al. 2010 | Warming | *Costaria costata* | China  (Dalian) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Gametophyte | Growth | Length |
| Gaitán-  Espitia et al. 2014 | Warming, Acidification,  Multiple stressors | *Macrocystis*  *pyrifera* | USA (California, Santa  Barbara) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Spore/ germling | Reproduction | Germination rate,  Ungerminated spores |
| Survival | Survival |
| Gao et al. 2013a | Warming | *Undaria pinnatifida* | Japan (Matsushima / Naruto) | Northeastern  Honshu / Central Kuroshio Current | Cold  Temperate Northwest  Pacific / Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Carbon, Nitrogen |
| Growth | Weight change |
| Survival | Survival |
| Gao et al. 2013b | Warming | *Undaria pinnatifida* | Japan (Okirai Bay / Matsushima / Naruto) | Northeastern  Honshu, Central Kuroshio Current | Cold  Temperate Northwest  Pacific, Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Nitrogen |
| Growth | Weight change |
| Net  primary productivity | GPmax |
| Respiration | RD |
| Survival | Survival |
| Gao et al. 2016 | Warming | *Ecklonia cava* | Japan (Izu Peninsula) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Nitrogen |
| Growth | Weight change |
| Pigments | Chlorophyll-*a* |
| Respiration | Oxygen evolution |
| Survival | Survival |
| Gao et al. 2017 | Warming | *Saccharina*  *japonica* | Japan (Hokkaido, Osatsube) | Northeastern  Honshu | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte, Adult  sporophyte | Biochemical composition | Nitrogen |
| Growth | Weight change |
| Net  primary productivity | GP |
| Pigments | Chlorophyll-*a* |
| Survival | Survival |
| Gao et al. 2019a | Warming, acidification,  multiple stressors | *Ecklonia stolonifera* | Korea (Jeonam, Jindo) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Fluorescence | Fv/Fm, rETRmax |
| Gametophyte | Growth | Elongation rate |
| Gao et al. 2019b | Warming, acidification,  multiple stressors | *Saccharina*  *japonica, Undaria pinnatifida* | Korea (Jeonam, Jindo) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Fluorescence | Fv/Fm, rETRmax, α |
| Gametophyte | Growth | Elongation rate |
| Gerard 1997a | Warming | *Saccharina*  *latissima* | USA (New Hampshire, Portsmouth) | Gulf of Maine/  Bay of Fundy | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Young sporophyte | Growth | Weight change |
| Survival | Density change |
| Gerard 1997b | Warming | *Saccharina*  *latissima* | USA (Maine, South Bristol / New York, Long  Island Sound) | Gulf of Maine/  Bay of Funday / Virginian | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Young sporophyte | Biochemical composition | Nitrogen, Proteins, Carbon |
| Fluorescence | Fv/Fm  reduction |
| Net  primary productivity | GPmax |
| Respiration | RD |
| Gerard & DuBois 1988 | Warming | *Saccharina*  *latissima* | USA (New York, Maine) | Virginian,  Gulf of Maine/  Bay of Fundy | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Young sporophyte | Fluorescence | α |
| Growth | Weight change |
| Net  primary productivity | GPmax |
| Pigments | Chlorophyll-*a* |
| Respiration | RD |
| González et al. 2018 | Warming, acidification,  multiple stressors | *Lessonia trabeculata* | Chile (Coquimbo, Puerto Aldea) | Central Chile | Warm Temperate Southeastern Pacific | Temperate South America | Gametophyte | Growth | Elongation rate |
| Reproduction | Sex ratio,  Oogonium formation, Reproductive  success |
| Spore/  germling | Germination rate |
| González et al. 2021 | Warming, acidification,  multiple stressors | *Lessonia trabeculata* | Chile (Coquimbo, El Frances) | Central Chile | Warm Temperate Southeastern Pacific | Temperate South America | Adult  sporophyte | Fluorescence | Fv/Fm |
| Spore/  germling | Reproduction | Germination rate |
| Gordillo et al. 2015 | Acidification | *Alaria*  *esculenta, Saccharina*  *latissima* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Young sporophyte | Biochemical composition | Carbon, Nitrogen, C:N ratio |
| Enzyme activity | CAext, NR  activity |
| Fluorescence | Fv/Fm, α, ETRmax |
| Growth | Weight change |
| Pigments | Chlorophyll-*a*, Carotenoids |
| Gordillo et al. 2016 | Warming, acidification,  multiple stressors | *Alaria*  *esculenta* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Young sporophyte | Biochemical composition | Carbon, Nitrogen, Proteins, Soluble carbohydrates,  Lipids, C:N ratio |
| Enzyme activity | CAext, NR |
| Fluorescence | Fv/Fm, Ek, α, ETRmax |
| Growth | Weight change |
| Pigments | Chlorophyll-*a* |
| Hargrave et al. 2017 | Warming | *Laminaria digitata, Laminaria ochrole-uca* | United Kingdom (Plymouth Sound) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Fluorescence | Fv/Fm |
| Growth | Elongation rate, Weight change |
| Stress  response | Phenolic content, Flavonoid content |
| Henkel & Hofmann 2008a | Warming | *Egregia menziesii* | USA (California,  Carmel and  Monterey Bay) | Northern  California | Cold  Temperate Northeast  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Stress  response | hsp70 expression |
| USA (California, Santa  Barbara) to  Mexico  (Todos Santos) | Southern  California Bight | Warm Temperate Northeast  Pacific |
| Henkel & Hofmann 2008b | Warming | *Undaria pinnatifida* | USA (California, Monterey Bay) | Northern  California | Cold  Temperate Northeast  Pacific | Temperate Northern  Pacific | Gametophyte | Stress  response | hsp70  expression |
| USA (California, Santa  Barbara to San  Diego) | Southern  California Bight | Warm Temperate Northeast  Pacific |
| Hoffman et al. 2003 | Warming | *Alaria marginata* | USA (Washington, Friday Harbor) | Puget Trough / Georgia Basin | Cold  Temperate Northeast  Pacific | Temperate Northern  Pacific | Spore/ germling | Growth | Number of cells |
| Reproduction | Germination rate |
| Hwang et al. 2018 | Warming | *Saccharina*  *japonica* | Korea (Haenam) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Fluorescence | Fv/Fm |
| Growth | Elongation rate |
| Iñiguez et al. 2016a | Acidification | *Alaria*  *esculenta* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Young sporophyte | Biochemical composition | Carbon, Nitrogen, C:N ratio,  δ13 C |
| Fluorescence | ETRmax, α, Ek, Fv/Fm |
| Growth | Weight change |
| Net  primary productivity | NP, GP, Carbon fixation rate, DOC  release rate, POC  release rate, Photosynthetic  quotient |
| Respiration | RD |
| Tissue health | FW:DW ratio |
| Iñiguez et al. 2016b | Warming, acidification,  multiple stressors | *Laminaria solidungula* / *Saccharina*  *latissima* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Adult  sporophyte / Young sporophyte | Biochemical composition | Carbon, Nitrogen, C:N ratio,  δ13 C |
| Fluorescence | ETRmax, α, Ek, Fv/Fm |
| Growth | Weight change |
| Net  primary productivity | NP, GP, Carbon fixation rate, DOC  release rate, Photosynthetic quotient |
| Respiration | RD |
| Tissue health | FW:DW ratio |
| Kang & Chung 2018 | Acidification | *Saccharina*  *japonica* | South  Korea (Jindo) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Biochemical composition | Carbon, Nitrogen, C:N ratio |
| Fluorescence | Fv/Fm |
| Growth | Weight change |
| Net  primary productivity | NP, O2  evolution inhibition rate, NH4+  uptake |
| King et al. 2018 | Warming | *Laminaria digitata, Laminaria ochrou-leuca* | United Kingdom (Cornwall) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Fluorescence | Fv/Fm |
| Stress  response | hsp70  expression |
| King et al. 2019 | Warming | *Laminaria digitata* | Scotland (Warbeth) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Stress  response | hsp70  expression |
| Scotland (Easdale), United Kingdom (Cornwall) | Celtic Seas |
| Komazawa et al. 2015 | Warming | *Ecklonia radicosa* | Japan (Izu-Oshima  Island) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Gametophyte | Growth | Area change |
| Young sporophyte |
| Leal et al. 2017a | Acidification | *Macrocystis*  *pyrifera, Undaria pinnatifida* | New  Zealand (Otago Harbour) | South New Zealand | Southern New  Zealand | Temperate  Australasia | Spore/ germling | Growth | Area change |
| Reproduction | Germination rate |
| Gametophyte | Growth | Area |
| Reproduction | Sex ratio |
| Leal et al. 2017b | Warming, Acidification,  multiple stressors | *Macrocystis*  *pyrifera, Undaria pinnatifida* | New  Zealand (Otago Harbour) | South New Zealand | Southern New  Zealand | Temperate  Australasia | Spore/ germling | Growth | Area change |
| Reproduction | Germination rate |
| Gametophyte | Growth | Area |
| Reproduction | Sex ratio |
| Leal et al. 2018 | Warming, Acidification,  multiple stressors | *Macrocystis*  *pyrifera, Undaria pinnatifida* | New  Zealand (Otago Harbour) | South New Zealand | Southern New  Zealand | Temperate  Australasia | Spore/ germling | Growth | Area change |
| Reproduction | Germination rate |
| Gametophyte | Growth | Area |
| Reproduction | Sex ratio |
| Lee & Brinkhuis 1988 | Warming | *Saccharina*  *latissima* | USA (New York, Long  Island Sound) | Virginian | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Gametophyte | Reproduction | Sex ratio |
| Li et al. 2020 | Warming | *Saccharina*  *latissima* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Young sporophyte | Fluorescence | Fv/Fm |
| Growth | Weight change |
| Pigments | Chlorophyll-*a*, Acc, VAZ, DPS |
| Liesner et al. 2020 | Warming | *Laminaria digitata* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Adult  sporophyte | Fluorescence | Fv/Fm, rETRmax, α, Ek, NPQ |
| Growth | Weight change |
| France (Quiberon) | South  European  Atlantic Shelf | Lusitanian | Temperate Northern  Atlantic | Biochemical composition | Carbon, Nitrogen, C:N ratio, Mannitol |
| Fluorescence | Fv/Fm, rETRmax, α, Ek, NPQ |
| Growth | Weight change |
| Pigments | Chlorophyll-*a*, VAZ : Chlorophyll-*a* ratio, DPS |
| France (Roscoff) / Germany (Helgoland) / Norway (Tromsø) | Celtic Seas / North Sea / Northern  Norway and  Finnmark) | Northern  European Seas | Temperate Northern  Atlantic | Biochemical composition | Carbon, Nitrogen, C:N  ratio, Mannitol |
| Fluorescence | Fv/Fm, rETRmax, α, Ek, NPQ |
| Growth | Weight change |
| Pigments | Chlorophyll-*a*, VAZ : Chlorophyll-*a*  ratio, DPS |
| Lind & Konar 2017 | Warming | *Eularia fistulosa, Nereocystis*  *luetkeana, Saccharina*  *latissima* | Alaska (Kachemak Bay) | Gulf of Alaska | Cold  Temperate Northeast  Pacific | Temperate Northern  Pacific | Spore/ germling | Survival | Density |
| Gametophyte | Growth | Germ tube length |
| Liu & Pang 2010 | Warming | *Saccharina*  *japonica* | China (Daban / Benniu / Zhen / Yanza / Fujian / Gaolv / Qingdao) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Proteins |
| Enzyme activity | Peroxidase, Glutathione reductase |
| Fluorescence | Fv/Fm, Fv/F0 |
| Growth | Elongation rate |
| Stress  response | Malond-ialdehyde, SOD  activity, CAT  activity |
| Liu et al. 2019 | Warming | *Saccharina*  *japonica* | China (Shandong Province, Rongcheng) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Enzyme activity | Peroxidase |
| Stress  response | SOD  activity, CAT  activity |
| Longp-huirt et al. 2013 | Acidification | *Saccharina*  *latissima* | Ireland (County Galway, Letterard) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Fluorescence | Ek |
| Net  primary productivity | CO2  uptake, Vmax |
| Lüning 1980 | Warming | *Laminaria digitata* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Gametophyte | Growth | Diameter |
| *Laminaria hyperborea* |
| *Saccharina*  *latissima* |
| Lüning & Neuschul 1978 | Warming | *Alaria marginata, Hedophyllum dentigerum, Hedophyllum*  *sessile, Laminaria sinclairii, Macrocystis*  *pyrifera* /  *Egregia menziesii, Laminaria forlowii, Macrocystis*  *pyrifera,*  *Pterygophora californica* | USA  (central California) / USA (California, Santa  Barbara) | Northern  California / Southern  California Bight | Cold Temperate Northeast  Pacific / Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Gametophyte | Growth | Length |
| Reproduction | Fertility |
| Mabin et al. 2013 | Warming | *Ecklonia radiata* | Australia (Tasmania, Bicheno) | Bassian | Southeast Australian Shelf | Temperate  Australasia | Gametophyte | Growth | Area, Number of cells |
| Young sporophyte | Area |
| Mabin et al. 2019 | Warming | *Macrocystis*  *pyrifera* | Australia (Tasmania,  Fortescue Bay) | Bassian | Southeast Australian Shelf | Temperate  Australasia | Young sporophyte | Biochemical composition | Nitrogen, Carbon, δ15 N, RNA, RNA : DNA  ratio, C:N  ratio,  δ13 C, DNA |
| Fluorescence | rETRmax, Ek, Fv/Fm |
| Growth | Weight change |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c*, Fx |
| Martins et al. 2017 | Warming | *Laminaria digitata* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Gametophyte | Growth | Area |
| Matson &  Edwards 2007 | Warming | *Eisenia*  *arborea* | USA (California, San  Diego) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Young sporophyte | Survival | Density |
| *Pterygophora californica* |
| Minich et al. 2018 | Warming, Acidification,  multiple stressors | *Macrocystis*  *pyrifera* | USA (California, San  Diego) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Growth | Weight change |
| Mohring et al. 2013 | Warming | *Ecklonia radiata* | Australia (Western  Australia, Shoalw-ater  Islands) | Leeuwin | Southwest Australian Shelf | Temperate  Australasia | Gametophyte | Growth | Area |
| Survival | Density |
| Mohring et al. 2014 | Warming | *Ecklonia radiata* | Australia (Bicheno) | Bassian | Southeast Australian Shelf | Temperate  Australasia | Gametophyte | Growth | Area |
| Australia (Fortesque) |
| Australia (Southport) |
| Australia (Encounter) | Western Bassian |
| Australia (Albany) | Leeuwin |
| Australia (Hamelin Bay) |
| Australia (Adelaide) | South Australian Gulfs |
| Australia (Yorke) |
| Australia (Marmion) | Houtman | West  Central  Australian Shelf | Survival | Density |
| Monteiro et al. 2021 | Warming | *Saccharina*  *latissima* | France (Brittany, Roscoff) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Young sporophyte | Biochemical composition | Carbon, Nitrogen, Mannitol, C:N ratio |
| Fluorescence | Fv/Fm |
| Growth | Weight change |
| Pigments | Chlorophyll-*a*, Acc, VAZ, DPS |
| Morita et al. 2003a | Warming | *Undaria pinnatifida* | Japan (Mugisaki) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Gametophyte | Growth | Area change |
| Japan (Gokasyo Bay) |
| Morita et al. 2003b | Warming | *Undaria pinnatifida* | Japan (Mugisaki) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Growth | Area change |
| Japan (Gokasyo Bay) |
| Muñoz et al. 2004 | Warming | *Macrocystis*  *pyrifera* | Chile  (Bahía Mansa / Metri) | Araucanian / Chiloense | Warm Temperate Southeastern Pacific / Magellanic | Temperate South America | Gametophyte | Growth | Diameter |
| Reproduction | Number of  oogonia |
| Survival | Density |
| Murúa et al. 2021 | Warming | *Macrocystis*  *pyrifera* | Chile (Puerto Montt) | Chiloense | Magellanic | Temperate South America | Gametophyte | Reproduction | Reproductive  success, Sex ratio |
| Chile  (Bahía  Inglesa) | Central Chile | Warm Temperate Southeastern Pacific |
| Muth et al. 2019 | Warming | *Alaria marginata, Costaria costata, Dictyoneurum reticulatum,*  *Eisenia*  *arborea, Egregia menziesii, Laminaria ephemera, Laminaria setchellii,*  *Lessoniopsis*  *littoralis, Macrocystis*  *pyrifera, Nereocystis*  *luetkeana, Postelsia palmiformis, Pterygophora californica* | USA (California, Big Creek Cove / Carmel Bay /  Soberanes Point / Stillwater Cove) | Northern  California | Cold  Temperate Northeast  Pacific | Temperate Northern  Pacific | Young sporophyte | Survival | Density |
| Canada (Vancouver Island) | Oregon, Washington,  Vancouver Coast and Shelf |
| USA (Washington,  Tatoosh Island) |
| USA (Washington, San Juan  Island) | Puget Trough / Georgia Basin |
| USA (California, Catalina / Los  Angeles / San  Diego) | Southern  California Bight | Warm Temperate Northeast  Pacific |
| Nepper-Davidsen et al. 2019 | Warming | *Saccharina*  *latissima* | Denmark (Southern  Kattegat) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Biochemical composition | Carbon, Nitrogen, Mannitol |
| Fluorescence | α, Fv/Fm, rETR, NPQ, Ec |
| Growth | Elongation rate, Weight change |
| Net  primary productivity | GP,  Carbon  acquisition |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c* : Chlorophyll-*a*  ratio, Fx : Chlorophyll-*a*  ratio, VAZ : Chlorophyll-*a*  ratio, DPS, Beta-carotene : Chlorophyll-*a*  ratio |
| Respiration | RD |
| Survival | Mortality |
| Nunes et al. 2016 | Acidification | *Saccharina*  *latissima* | United Kingdom (Plymouth Sound) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Growth | Elongation rate, Perforation area |
| Net  primary productivity | NP |
| Respiration | RD |
| Stress  response | DMSP |
| Olischl-äger et al. 2012 | Acidification | *Laminaria hyperborea* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Spore/ germling | Reproduction | Germination rate |
| Gametophyte | Reproductive  success |
| Young sporophyte | Fluorescence | Fv/Fm, rETRmax |
| Growth | Weight change |
| Net  primary productivity | NP |
| Pigments | Chlorophyll-*a* |
| Stress  response | Phlorotannin content |
| Tissue health | DW:WW ratio |
| Adult  sporophyte | Fluorescence | Fv/Fm, rETRmax |
| Reproduction | Weight gain  during  sorus  formation |
| Olischl-äger et al. 2014 | Warming, acidification,  multiple stressors | *Saccharina*  *latissima* | Germany (Helgoland) / Norway (Svalbard, Spitsbergen) | North Sea / North and East Barents Sea | Northern  European Seas /  Arctic | Temperate Northern  Atlantic / Arctic | Young sporophyte | Biochemical composition | Carbon, Soluble carbohydrates,  Nitrogen, Proteins, Lipids, C:N ratio |
| Tissue health | FW:DW ratio |
| Olischl-äger et al. 2017 | Warming, acidification,  multiple stressors | *Saccharina*  *latissima* | Germany (Helgoland) / Norway (Svalbard, Spitsbergen) | North Sea / North and East Barents Sea | Northern  European Seas /  Arctic | Temperate Northern  Atlantic / Arctic | Young sporophyte | Biochemical composition | εp |
| Enzyme activity | RuBisCO |
| Fluorescence | Fv/Fm |
| Growth | Weight change |
| Net  primary productivity | NP |
| Pigments | Accessory  pigment : Chlorophyll-*a*  ratio, Beta-carotene, Beta-carotene : Chlorophyll-*a*  ratio, Chlorophyll-*a*, Chlorophyll-*c*, Chlorophyll-*c* : Chlorophyll-*a*  ratio, D1 protein, DPS, Fx, Fx : Chlorophyll-*a* ratio, V, V : Chlorophyll-*a* ratio, VAZ, VAZ : Chlorophyll-*a*  ratio, Z, Z : Chlorophyll-*a*  ratio |
| Olischl-äger & Wiencke 2013 | Warming | *Alaria*  *esculenta* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Spore/ germling | Reproduction | Germination rate |
| *Laminaria digitata* |
| Oppliger et al. 2011 | Warming | *Lessonia nigrescens* | Chile (El Quisco / Las  Cruces / Valdivia) | Araucanian | Warm Temperate Southeastern Pacific | Temperate South America | Gametophyte | Reproduction | Sex ratio |
| Chile (Pan de Azucar) | Central Chile |
| Chile (Los Verdes) | Humboldtian |
| Oppliger et al. 2012 | Warming | *Lessonia nigrescens* | Chile (Las Cruces / Chañaral de  Aceituno, Choros Ventana / Iquique and  Carrizal Bajo) | Araucanian /  Central Chile / Humboldtian | Warm Temperate Southeastern Pacific | Temperate South America | Spore/ germling | Reproduction | Germination rate |
| Gametophyte | Frequency of  females with  vegetative growth, Oogonium formation, Reproductive  success, Sex ratio |
| Survival | Survival |
| Paine et al. 2021 | Warming | *Lessonia corrugata* | Australia (Tasmania, Crayfish Point) | Bassian | Southeast Australian Shelf | Temperate  Australasia | Gametophyte | Growth | Area |
| Reproduction | Oogonium formation |
| Pang et al. 2007 | Warming | *Saccharina*  *japonica* | China  (Fujian / Qingdao) | East China Sea /  Yellow Sea | Warm Temperate Northwest  Pacific / Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Fluorescence | Fv/Fm |
| Growth | Elongation rate |
| Parages et al. 2013 | Warming | *Laminaria solidungula, Saccharina*  *latissima* | Norway (Svalbard, Blomstrand-halvøya) | North and East  Barents Sea | Arctic | Arctic | Young sporophyte | Fluorescence | Fv/Fm |
| Stress response | 36 kDa band  intensity,  42 kDa band  intensity,  p-38-like  protein phosphorylation |
| Park et al. 2017 | Warming | *Alaria*  *esculenta, Saccharina*  *latissima* | Norway (Svalbard, Blomstrand-halvøya) | North and East  Barents Sea | Arctic | Arctic | Gametophyte | Fluorescence | α, Ek, Fv/Fm, NPQ, rETRmax |
| Growth | Area,  Diameter, Length, Number of cells |
| Reproduction | Reproductive  success, Sex ratio |
| Pereira et al. 2011 | Warming | *Laminaria ochrole-uca* | France (Brittany, Morlaix Bay) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Gametophyte | Reproduction | Sex ratio |
| Survival | Survival |
| Pereira et al. 2015 | Warming | *Laminaria ochrole-uca* | France (Brittany) | Celtic Seas | Northern  European Seas | Temperate Northern  Atlantic | Adult  sporophyte | Fluorescence | Fv/Fm |
| Portugal | South  European  Atlantic Shelf | Lusitanian |
| Qiu et al. 2019 | Warming, acidification,  multiple stressors | *Ecklonia radiata* | Australia (Charlesworth Bay) | Tweed-Moreton | East Central  Australian Shelf | Temperate  Australasia | Young sporophyte | Fluorescence | Fv/Fm |
| Tissue health | Number of  blisters |
| Roelda 2009 | Warming | *Alaria*  *esculenta* | Norway (Svalbard, Blomstrand-halvøya) | North and East  Barents Sea | Arctic | Arctic | Spore/ germling | Fluorescence | Fv/Fm, NPQ,  Photoinhibition |
| *Laminaria digitata* |
| *Saccharina*  *latissima* |
| Roleda 2016 | Warming | *Laminaria solidungula* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Spore/ germling | Fluorescence | Fv/Fm |
| Growth | Relative size |
| Rothäusler et al. 2009 | Warming | *Macrocystis*  *pyrifera* | Chile (Coquimbo) | Central Chile | Warm Temperate Southeastern Pacific | Temperate South America | Young sporophyte | Growth | Weight change, Elongation rate |
| Chile (Calfuco) | Araucanian |
| Rothäusler et al. 2011a | Warming | *Macrocystis*  *pyrifera* | Chile (Coquimbo / Calfuco) | Central Chile / Araucanian | Warm Temperate Southeastern Pacific | Temperate South America | Young sporophyte | Biochemical composition | Carbon, Nitrogen |
| Enzyme activity | Total CA |
| Fluorescence | α, Ek, ETRmax, Fv/Fm |
| Pigments | Carotenoids, Chlorophyll-*a*, Chlorophyll-*c* |
| Rothäusler et al. 2011b | Warming | *Macrocystis*  *pyrifera* | Chile (Los  Vilos,  Caleta San Pedro) | Central Chile | Warm Temperate Southeastern Pacific | Temperate South America | Adult  sporophyte | Fluorescence | Fv/Fm |
| Growth | Elongation rate, weight change |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c* |
| Reproduction | Reproductive area  allocation |
| Sakanishi et al. 1989 | Warming | *Ecklonia cava* | Japan (Shimoda,  Nabeta Bay) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Net  primary productivity | NP |
| Respiration | RD |
| Sánchez‐Barredo et al. 2020 | Warming | *Macrocystis*  *pyrifera* | Mexico (Baja  California,  Bahía  Todos Santos) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Nitrogen,  Total non-structural carbohydrates |
| Fluorescence | α, ETRmax, Fv/Fm, NPQ, YII |
| Net  primary productivity | Nitrate  uptake |
| Pigments | Carotenoids, Chlorophyll-*a*, Chlorophyll-*c* |
| Stress response | Antioxidant  activity, Lipid peroxidation, Total  phenolic content |
| Sato et al. 2020 | Warming | *Saccharina*  *sculpera* | Japan (Hokkaido  Island,  Hakodate) | Sea of  Japan/  East Sea | Cold Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Fluorescence | Fv/Fm |
| Net  primary productivity | NPmax |
| Respiration | RD |
| Sato et al. 2021 | Warming | *Undaria pinnatifida* | Japan (Miyagi, Matsushima Bay) | Northeastern  Honshu | Cold Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Fluorescence | Fv/Fm, YII |
| Net  primary productivity | NPmax |
| Respiration | RD |
| Schesc-honk et al. 2019 | Warming | *Laminaria solidungula* | Norway (Svalbard, Spitsbergen) | North and East  Barents Sea | Arctic | Arctic | Adult  sporophyte | Biochemical composition | Laminarin |
| *Saccharina*  *latissima* |
| Schmid et al. 2020 | Warming | *Macrocystis*  *pyrifera* | Australia (Tasmania, Bruny  Island) | South New Zealand | Southern New  Zealand | Temperate  Australasia | Adult  sporophyte | Biochemical composition | Lipids, MUFA, PUFA, SFA |
| Serisa-wa et al. 2001 | Warming | *Ecklonia cava* | Japan (Shimoda / Tosa Bay) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Net  primary productivity | NP |
| Respiration | RD |
| Shukla & Edwards 2017 | Warming, acidification, multiple stressors | *Macrocystis*  *pyrifera* | USA (California, San  Diego) | Southern  California Bight | Warm Temperate Northeast  Pacific | Temperate Northern Pacific | Spore/ germling | Survival | Density |
| Gametophyte | Growth | Length |
| Survival | Survival |
| Young sporophyte | Growth | Length |
| Survival | Density |
| Simonson et al. 2015a | Warming | *Agarum clathratum, Laminaria digitata, Saccharina*  *latissima* | Canada (Nova Scotia, Halifax) | Scotian Shelf | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Adult  sporophyte | Growth | Elongation rate |
| Tissue health | Breaking stress, Maximum strain,  Tissue loss |
| Simonson et al. 2015b | Warming | *Agarum clathratum, Laminaria digitata, Saccharina*  *latissima* | Canada (Nova Scotia, Halifax) | Scotian Shelf | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Adult  sporophyte | Biochemical composition | C:N  ratio |
| Tissue health | Tissue loss |
| Stress response | Phlorotannin content |
| Staehr & Wernberg 2009 | Warming | *Ecklonia radiata* | Australia (Hamelin Bay /  Marmion Lagoon / Jurien Bay) | Leeuwin / Houtman | Southwest Australian Shelf / West  Central Australian Shelf | Temperate  Australasia | Adult  sporophyte | Fluorescence | Ec, Ek |
| Net  primary productivity | NPmax |
| Respiration | RD |
| Steinhoff et al. 2008 | Warming | *Laminaria hyperborea* | Germany (Helgoland) | North Sea | Northern  European Seas | Temperate Northern  Atlantic | Spore/ germling | Reproduction | Germination rate |
| Supratya et al. 2020 | Warming | *Nereocystis*  *luetkeana* | Canada (British Columbia, Vancouver) | Puget Trough / Georgia Basin | Cold Temperate Northeast  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Growth | Elongation rate,  Diameter change |
| Swanson & Fox 2007 | Acidification | *Nereocystis*  *luetkeana, Saccharina*  *latissima* | Canada (British Columbia,  Barkley Sound) | Oregon, Washington,  Vancouver Coast and Shelf | Cold Temperate Northeast  Pacific | Temperate Northern  Pacific | Young sporophyte | Growth | Area, weight |
| Stress  response | Phlorotannin content |
| Terada et al. 2016 | Warming | *Ecklonia radicosa* | Japan (Kagoshima Prefecture, Nagashima) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Net  primary productivity | NP |
| Respiration | RD |
| Thom 1996 | Acidification | *Nereocystis*  *luetkeana* | USA (Washington,  Sequim) | Puget Trough/ Georgia Basin | Cold  Temperate Northeast  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Net  primary productivity | NPmax |
| Thornber et al. 2004 | Warming | *Undaria pinnatifida* | USA (California, Monterey) | Northern  California | Cold  Temperate Northeast  Pacific | Temperate Northern  Pacific | Gametophyte | Survival | Density |
| Young sporophyte |
| USA (California,  Santa Barbara) | Southern  California Bight | Warm Temperate Northeast  Pacific |
| Umanzor et al. 2021 | Warming | *Macrocystis*  *pyrifera* | Mexico (Baja  California,  Bahía  Todos Santos) | Southern  California Bight | Warm Temperate NortheastPacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Nitrogen, Soluble carbohydrates |
| Fluorescence | α, Ec, ETRmax, Fv/Fm, NPQ, YII |
| Growth | Elongation rate |
| Net  primary productivity | GPmax,  Nitrate  uptake, NPmax, Photosynthesis : Respiration ratio |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c*, Fx |
| Respiration | RD |
| Stress  response | Antioxidant  activity,  lipid  peroxidation, total phenolic content |
| Watanabe et al. 2014 | Warming | *Undaria pinnatifida* | Japan (Kagoshima, Ibusuki, Yamagawa) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Gametophyte | Growth | Number of cells, weight change |
| Adult  sporophyte | Fluorescence | YII |
| Net  primary productivity | NPmax |
| Respiration | RD |
| Wernberg et al. 2016 | Warming | *Ecklonia radiata* | Australia (Jurien Bay /  Marmion  Lagoon / Hamelin Bay) | Houtman / Leeuwin | West  Central Australian Shelf / Southwest Australian Shelf | Temperate  Australasia | Adult  sporophyte | Net  primary productivity | NP |
| Respiration | RD |
| Wilson et al. 2015 | Warming | *Laminaria digitata* | Canada (Nova Scotia) | Scotian Shelf | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Young sporophyte | Biochemical composition | Carbon, Nitrogen |
| Growth | Weight change |
| Xiao et al. 2015 | Warming | *Ecklonia radiata* | Australia (Marmion) | Houtman | West  Central  Australian Shelf | Temperate  Australasia | Young sporophyte | Growth | Elongation rate, weight change |
| Fluorescence | Fv/Fm |
| Xu et al. 2015 | Acidification | *Saccharina*  *japonica* | China (Yellow Sea, Sungo Bay) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Spore/ germling | Reproduction | Germination rate |
| Gametophyte | Number of  oogonia,  Oogonium formation, Reproductive  success, Sex ratio |
| Fluorescence | α, Fv/Fm, rETR, YII |
| Growth | Diameter, number of cells |
| Young sporophyte | Biochemical composition | C:N ratio, Carbon, Nitrogen |
| Fluorescence | α, Fv/Fm, rETR, YII |
| Growth | Length |
| Pigments | Chlorophyll-*a*, Chlorophyll-*c*, Chlorophyll-*a* : Chlorophyll-*c*  ratio |
| Survival | Density |
| Xu et al. 2017 | Acidification | *Saccharina*  *japonica, Undaria pinnatifida* | China (Sungo Bay) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Growth | Weight change |
| Net  primary productivity | NP |
| Respiration | RD |
| *Macrocystis*  *pyrifera* | Mexico (Santo Tomás) | Southern  California Bight | Warm Temperate Northeast  Pacific | Young sporophyte | Growth | Weight change |
| Net  primary productivity | NP |
| Respiration | RD |
| Xu et al. 2019 | Warming, Acidification,  multiple stressors | *Macrocystis*  *pyrifera, Undaria pinnatifida* | China (Yellow Sea, Sungo Bay | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Growth | Weight change |
| Stress  response | Iodine  accumulation |
| *Saccharina*  *japonica* |
| Young sporophyte | Fluorescence | Fv/Fm |
| Stress  response | Iodine  accumulation,  Iodine  efflux |
| Yokohama 1973 | Warming | *Undaria pinnatifida* | Japan (Shimoda, Izu  Peninsula) | Central Kuroshio Current | Warm Temperate Northwest  Pacific | Temperate Northern  Pacific | Adult  sporophyte | Net  primary productivity | NP |
| Respiration | RD |
| Young et al. 2021 | Acidification | *Saccharina*  *latissima* | USA (New York, Moriches Bay) | Virginian | Cold  Temperate Northwest  Atlantic | Temperate Northern  Atlantic | Adult  sporophyte | Biochemical composition | Carbon, Nitrogen, C:N ratio,  δ13 C |
| Growth | Weight change |
| Zhang et al. 2013 | Warming | *Saccharina*  *japonica* | China (Yellow Sea) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Spore/ germling | Reproduction | Germination rate |
| Gametophyte | Growth | Length, Area |
| Survival | Survival |
| Zhang et al. 2020 | Acidification | *Saccharina*  *japonica* | China (Sungo Bay) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | 2-oxoglutarate,  Alanine, Alginic acid,  Alpha-linolenic acid, Amino acid,  Arachidonic acid,  Arginine, Aspartate, C:N ratio,  Carbon, Cellulose, Citrate, Cysteine, EPA, Eicosatrienoic acid, Free  arginine, Free  aspartate, Free  glutamine, Fucoidan, Fumarate, Gamma-linolenic acid,  Glutamine, Glycine, Histidine, Isoleucine, Laminarin, Leucine, Linoleic acid,  Lysine, Malate, Mannitol,  Methionine,  Nitrogen,  Oxaloacetate,  Phenylalanine,  Proline, Pyruvate, Serine, Soluble carbohydrates, Succinate, Threonine, Tyrosine, Valine |
| Enzyme activity | Glutamate synthase, Glutamine synthetase, Isocitrate dehydrogenase, Pyruvate kinase |
| Growth | Elongation rate, Weight change, Diameter change |
| Zhou et al. 2010 | Warming | *Saccharina*  *japonica* | China (Shandong Province, Yantai Sea Farm) | Yellow Sea | Cold  Temperate Northwest  Pacific | Temperate Northern  Pacific | Young sporophyte | Biochemical composition | Proteins |
| Enzyme activity | Glutathione peroxidase, Peroxidase,  Phenylalanine  ammonia-lyase,  Polyphenol  oxidase |
| Pigments | Chlorophyll-*a* |
| Stress  response | CAT  activity, Hydrogen  peroxide, Malondialdehyde, SOD  activity |

Abbreviations: α, light affinity/photon yield; Acc, Accessory pigment pool; CA, Carbonic anhydrase; CAext, external carbonic anhydrase; CAint, internal carbonic anhydrase; DPS, De-epoxidation state; DW, Dry weight; EC, Compensation irradiance; EK, Saturation irradiance; εP, Isotopic fractionation of organic carbon production; EPA, eicosapentaenoic acid; Fv/Fm, maximum quantum yield of photosynthesis; FW, Fresh weight; Fx, Fucoxanthin; GP, Gross photosynthesis; MDH, Malate dehydrogenase; M-1-PDH, mannitol-1-phosphate dehydrogenase; MUFA, Monounsaturated fatty acids; NPQ, non-photosynthetic quenching; NP, Net photosynthesis; NPmax, Maximum net photosynthetic rate; NR, Nitrate reductase; PUFA, polyunsaturated fatty acids; RD, dark respiration rate; SFA, saturated fatty acids; SOD, Superoxide dismutase; V, Violaxanthin; VAZ, Xanthophyll cycle pigment pool; WW, Wet weight; Z, Zeaxanthin.

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