Stereoselective Synthesis of Trienoic Acids: Synthesis of Retinoic Acids and Analogues

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Abstract: Stereoselective construction of conjugated trienoic acids was achieved through two successive Stille reactions, the first step consisting of the coupling of (*E*)-1,2-bis(tributylstannyl)ethene and tributylstannyl (*Z*)- or (*E*)-3-iodoalk-2-enoates. Two different routes were used for the second step: (1) cross-coupling of the stannyldienoic acid reagents and vinyl iodides, or (2) cross-coupling of vinylstannane reagents and the tributylstannyl 5-iodopenta-2,4-dienoates generated by iododestannylation of stannyldienes. Vinylstannanes synthesized by stannylmetalation of the Negishi dienyne derived from β- or α-ionone and safranal thus provided access to stereodefined retinoic acids. Some retinoid and yne analogues were also prepared by Sonogashira coupling.

Key words: Stille reaction, cross-coupling, tin compounds, trienoic acids, retinoic acids, polyenic acids

Introduction

Polyenic compounds with fixed configurations are found in many natural products such as retinoids or polyenic macrolides (e.g., mycoticin, roxatoxin). Retinoids are also metabolites, derivatives, and synthetic analogues of vitamin A. They bind to and activate nuclear retinoid receptors, which function as ligand-dependent transcription factors.[1] All-*trans*-retinoic acid (ATRA), (13*Z*)-retinoic acid (13-*cis*-RA),[2] and other retinoids are known to modulate the proliferation and differentiation of a variety of cell types through activation of their intracellular retinoid receptors. These receptors are divided into two distinct classes, the retinoic acid receptors (RARs, subtypes α, β, and γ) and the retinoid X receptors (RXRs, subtypes α, β, and γ), which have retinoic acids as ligands.[3] Several members of this class are used for the treatment of dermatological diseases and certain cancers.[4,5] The search for new methods of stereocontrolled synthesis is therefore of current interest.

In the past, conjugated polyenes have been constructed by Wittig-type approaches,[6] Peterson olefination, or sulfone-based olefination (Julia coupling).[7,8] Conjugated polyenes can also be synthesized by several other methods such as the Horner–Emmons reaction, the Stille approach, Suzuki coupling, and McMurry coupling. Linstrumelle et al. reported the easy construction of these compounds by successive Sonogashira-type reactions from (*Z*)- or (*E*)-dichloroethene.[9] Owing to its mild experimental conditions, the Stille cross-coupling reaction[10] has also emerged as a key step in various methods of total synthesis of natural products such as leinamycin,[11] macrolactin A,[12] des-epoxy-rosaramycin,[13] and limocrocin.[14] In connection with our ongoing work[15] on the Stille reaction for which substrates bearing an unprotected acid function are used, we wanted to develop direct and flexible routes yielding retinoic acids and analogues. We describe here the synthesis of all-*trans*-, (13*Z*)-, and (9-*nor*)-retinoic acids, and some retinoid and yne analogues derived from β- or α-ionone and safranal.[16,17] Our retrosynthesis strategy (Scheme 1) is based on the coupling of two building blocks **A** and **B** or **C** and starts from commercially available β- or α-ionone or safranal and alk-2-ynoic acids.

Results and Discussion

Stannylcupration of Alk-2-ynoic Acids

Over the last decade, functionalized vinylstannane reagents have emerged as valuable tools in organic synthesis.[18] Because of their wide range of reaction possibilities, especially in vinyl transfer in palladium-catalyzed cross-coupling, they have been used in key steps in total synthesis.[19–24]

We planned to study the synthesis of a great number of vinylstannanes and vinyl iodides bearing an unprotected carboxylic acid function, as part of a program dealing with the reactivity of unprotected iodovinylic acids and organometallic reagents under palladium-complex catalysis.[15] We have previously studied the stannylmetalation of alk-2-ynoic acids (Scheme 2)[25–27] and found that the best results were obtained with the high-order cyanocuprate $(Bu_3Sn)(Bu)CuLi{\cdot}LiCN$ (2.3 equiv); this afforded fair yields of the *E*-isomers.[25,26] We obtained the same results with 3-substituted alk-2-ynoic acids **1a**–**h**, which were transformed into vinylstannanes **2a**–**j** and, after subsequent iodine treatment, into the corresponding 3-iodoalk-2-enoic acids **3a**–**j** (Scheme 2, Table 1). The reactions proceeded with complete regio- and stereoselectivity in each case. It should be noted that the same results were

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obtained in the stannylmetalation of the corresponding tributylstannyl esters **2a′**–**j′**.

Attempts to incorporate a methyl group by quenching the vinylcopper intermediate with methyl iodide failed, even in the presence of 30 equivalents hexamethylphosphoramide (this agrees with the results of the stannylcupration of diethoxypropyne[28]). It should be noted that for iodine quenching (entry 10), the reaction was only completed after 48 hours at 0 °C. As recently reported for the stannylcupration in the presence of methanol,[29] we also observed that the addition of methanol (110 equiv) contributed to a slight increase in the yields (4–7%).

Synthesis of Dienoic Acids

The synthesis of dienoic acids **4** by palladium-catalyzed cross-coupling between 3-iodoalk-2-enoic acids **3** and vinylstannanes was achieved as shown in Scheme 3. The vinylstannanes were used with 3% bis(acetonitrile)dichloropalladium(II) in *N*,*N*-dimethylformamide as solvent. The mild experimental conditions of the Stille cross-

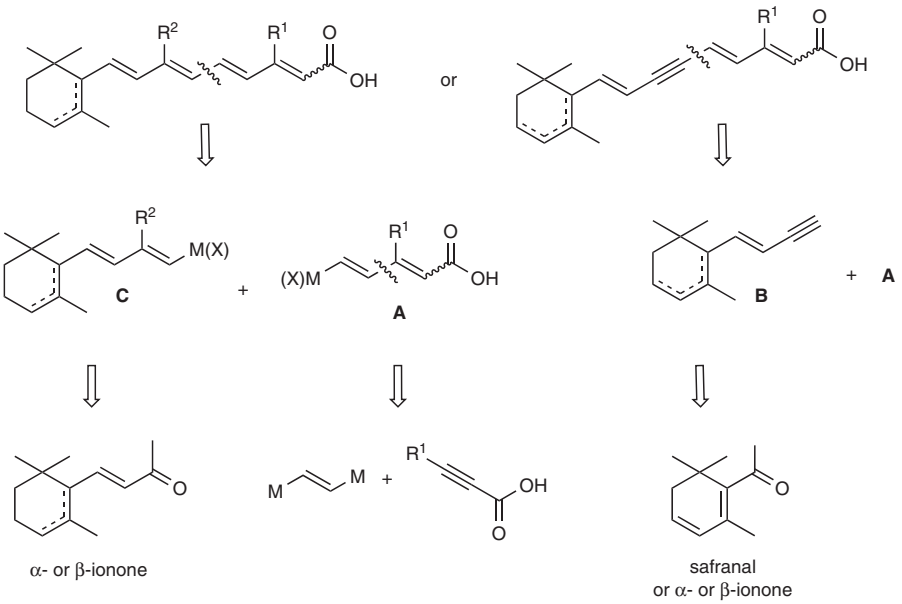
Biographical Sketches

Mohamed Abarbri was born in 1966 in Alhoceima (Marocco). In 1995 he obtained his PhD in Chemistry at the University of Tours. After postdoctoral studies in the laboratory of Professor Paul Knochel at the University of Marburg, he became lecturer (1996) and full professor (2002) at the University of Tours. His research interests include new synthetic methods, development of new organotin reagents, ultrasound chemistry, and synthesis of perfluoro compounds.

Jean-Luc Parrain obtained his PhD in Chemistry in 1990 at the University of Nantes (France) under the supervision of Professor Jean-Paul Quintard. After postdoctoral studies in the laboratory of Professor Steve Davies at the University of Oxford, he joined the CNRS as Chargé de Recherche at the laboratory of Organic Synthesis of the University of Nantes. In 1995, he moved to the University of Marseille and was then appointed a CNRS director of research in 2001. His research interests include new catalytic reactions toward new synthetic methods, development of new organotin and silicon reagents, and total synthesis of natural compounds.

Alain Duchêne was born in Tours (France) in 1947. He studied organic chemistry at the Faculty of Sciences, Bordeaux I University. After postdoctoral studies in the laboratory of Professor Ryoji Noyori at the University of Nagoya (1992), he was promoted to full professor in 1997 at the University of Tours. His research interests include new synthetic methods, development of new organogermanium or tin reagents, ultrasound chemistry, and synthetic organic materials.

Jérôme Thibonnet, born in 1971 in Joinville (France), received his PhD in 1999 from the University of Tours where he worked on the total synthesis of retinoids under the supervision of Professor Alain Duchêne. After postdoctoral studies in the laboratory of Professor Paul Knochel at the University of Munich, he joined the University of Aix-Marseille III as Ingénieur de Recherche at the laboratory of Professor Maurice Santelli (2000). He became lecturer at the University of Tours in 2003. His research interests include new synthetic methods, development of new organotin reagents, and total synthesis of natural compounds.



Scheme 1 Retrosynthetic strategy for the preparation of retinoid acids from alk-2-ynoic acids and α- or β-ionone or safranal

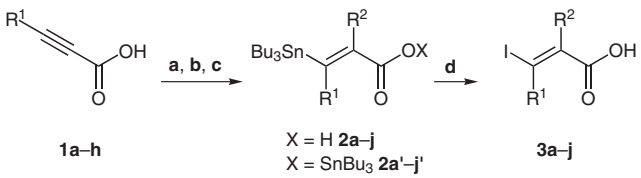
Table 1 Yields in the Stannylcupration of 3-Substituted Alk-2-ynoic Acids

Entry	Starting material **1**	R^1	R^2	Intermediate **2**	Yield of **2**[a] (%)	Product **3**	Yield of **3**[b] (%)
1	**1a**	H	H	**2a**	65	**3a**[15c]	58
2	**1b**	Me	H	**2b**	63	**3b**[27]	56
3	**1c**	Et	H	**2c**	68	**3c**	60
4	**1d**	Pr	H	**2d**	64	**3d**	57
5	**1e**	$(CH_2)_4Me$	H	**2e**	72	**3e**[27]	66
6	**1f**	Ph	H	**2f**	62	**3f**	59
7	**1g**	TMS	H	**2g**	55	**3g**	51[c]
8	**1h**	MOM	H	**2h**	72	**3h**	63
9	**1b**	Me	D	**2i**	60	**3i**	58
10	**1b**	Me	I	**2j**	45	**3j**	38

[a] Conversion based on **1**.
[b] Yields of isolated products **3** based on alkynoic acids **1**.
[c] The desilylated product also formed (5–10%).

coupling reaction resulted in good yields of dienoic acids **4a–j** (Table 2).

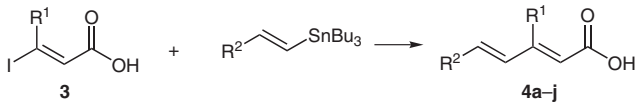
Surprisingly, cross-coupling between alkenoic acid **3h** and tributyl(vinyl)stannane gave cyclohexene **4k** resulting from a Diels–Alder reaction between two molecules of the expected dienoic acid (Scheme 4). We were unable to reproduce this reaction with other iodoalkenoic acids and tributyl(vinyl)stannane.



Scheme 2 Synthesis of 3-iodoalk-2-enoic acids by stannylcupration of alk-2-ynoic acids. *Reagents and conditions*: (a) $(Bu_3Sn)(Bu)CuLi{\cdot}LiCN$ (2.3 equiv), THF, –78 °C, 1 h; (b) NH_4Cl (R^2 = H), D_2O (R^2 = D), or I_2 (R^2 = I); (c) SiO_2 (X = H), or no treatment (X = $SnBu_3$); (d) I_2, Et_2O.

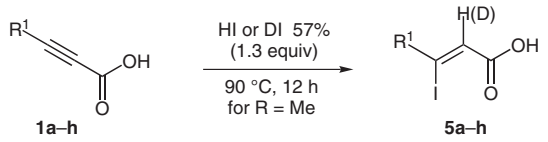
Table 2 Yields of Alka-2,4-dienoic Acids Synthesized by Cross-Coupling of 3-Iodoalk-2-enoic Acids with Vinylstannanes

Entry	Starting material **3**	R^1	R^2	Product **4**	Yield (%)
1	**3b**	Me	H	**4a**[27]	74
2	**3b**	Me	TMS	**4b**[27]	65
3	**3b**	Me	Ph	**4c**[27]	68
4	**3c**	Et	H	**4d**	77
5	**3c**	Et	TMS	**4e**	82
6	**3c**	Et	Ph	**4f**	84
7	**3c**	Et	$CH_2CH(OEt)_2$	**4g**	62
8	**3g**	TMS	H	**4h**	76
9	**3g**	TMS	TMS	**4i**	75
10	**3a**	H	TMS	**4j**	82



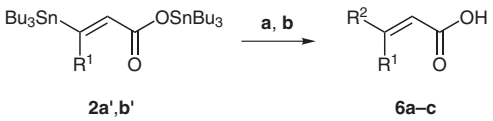
Scheme 3 Synthesis of alka-2,4-dienoic acids from 3-iodoalk-2-enoic acids and vinylstannanes. *Reagents and conditions*: $[PdCl_2(NCMe)_2]$ (5%), DMF, r.t., 3 h.

The synthesis of (*Z*)-3-iodoalk-2-enoic acids **5**, the counterparts of (*E*)-acids **4**, by hydroiodation of alk-2-ynoic acids **1a–h** with an aqueous solution of hydroiodic acid, as well as the reactivity of acids **5** with vinylstannanes have already been described (Scheme 5).[15b,27,30]



Scheme 5 Synthesis of (*Z*)-3-iodoalk-2-enoic acids by hydroiodation of alk-2-ynoic acids

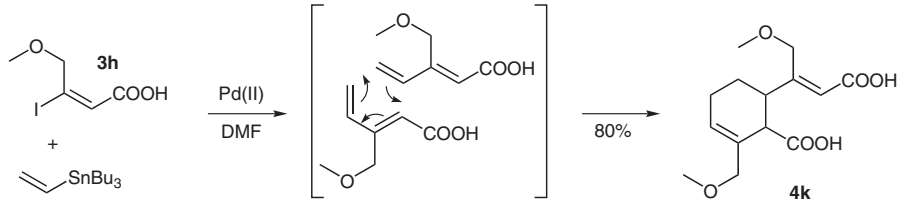
By a reaction similar to that described for acids **3** above, cross-coupling of 3-stannylalk-2-enoates **2a′** or **2b′** with a vinyl iodide or *p*-toluenesulfonyl chloride yielded alkenoic acids **6a–c** after deprotection of the carboxy function (Scheme 6, Table 3).



Scheme 6 Palladium-catalyzed cross-coupling of 3-stannylalk-2-enoates with organohalides. *Reagents and conditions*: (a) R^2X (1.1 equiv), $[PdCl_2(NCMe)_2]$ (5%), DMF, r.t., 3 h; (b) sat. KF, 1 M HCl.

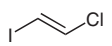
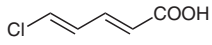
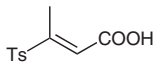
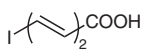
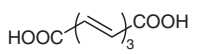
Synthesis of Dienynoic Acids and Trienoic Acids

Attempts to use (*E*)-1,2-bis(tributylstannyl)ethene[31] as vinylstannylation reagent with acids **3** or **5** failed. However, studies related to the synthesis of 4-arylbut-3-enoic acids through the Stille approach showed that protection of the carboxy function as a tributylstannyl ester group, for example, resulted in a considerable increase in yield.[15d,32] Stille coupling of 3-iodoalk-2-enoic acids **3** or **5** protected as their tributyltin esters with (*E*)-1,2-bis(tributylstannyl)ethene (1.1 equiv) in the presence of a catalytic amount (5 mol%) of bis(acetonitrile)dichloropalladium(II) stereospecifically provided stannylalkadienoates **7**, with retention of the configurations of the two double bonds (Scheme 7, Table 4).[33] The reaction of (*E*)-1,2-



Scheme 4 Cross-coupling between an alkenoic acid and a vinylstannane followed by a Diels–Alder reaction between two product molecules

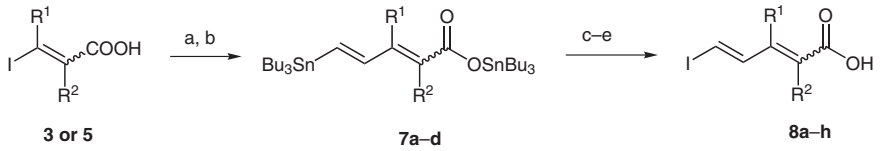
Table 3 Yields of Alkenoic Acids Synthesized by Cross-Coupling of 3-Stannylalk-2-enoates with Organohalides

Entry	Starting material **2**	R^1	R^2X	Product **6**	No	Yield (%)
1	**2a′**	H			**6a**	62
2	**2b′**	Me	TsCl		**6b**	68
3	**2a′**	H			**6c**	75

bis(tributylstannyl)ethene with iodovinylic esters (such as methyl or ethyl esters) under the same experimental conditions yielded products resulting from a double cross-coupling reaction.[34] Without stannyldienoates **7** being purified first, an iododestannylation reaction in diethyl ether at room temperature quantitatively yielded pure and unprotected 5-iodoalka-2,4-dienoic acids **8**, without isomerization of the α double bond, and with retention of the configuration of the second double bond (Scheme 7).

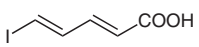
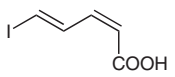
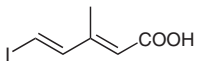
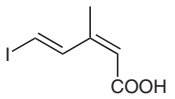
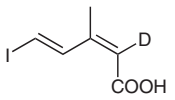
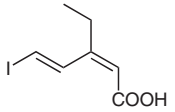
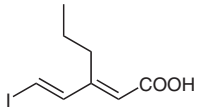
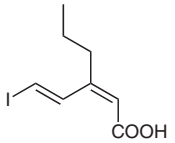
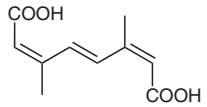
Bis-coupling products[35] or tributylstannyl-substituted products[36] were never observed when 1.1 equivalents of (*E*)-1,2-bis(tributylstannyl)ethene were used. The NOESY NMR experiment on **8d** confirmed the retention of the *Z*-stereochemistry of the α double bond. When 0.5 equivalents of (*E*)-1,2-bis(tributylstannyl)ethene were used, only the bis-coupling product **8i** formed (Table 4, entry 9).

By a similar procedure, iododienoic acids **8a**, **8b**, or **8d** underwent cross-coupling with vinylstannanes, yielding trienoic acids **9a–f** (Scheme 8, Table 5). The coupling of an tributyl(ethynyl)stannane also took place, giving dienynoic acid **9g** in 79% yield and without polymerization (Table 5, entry 7), again proving the mildness of these experimental conditions.

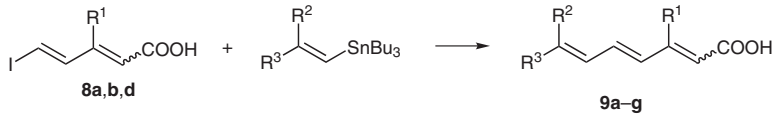


Scheme 7 Synthesis of 5-iodoalka-2,4-dienoic acids by palladium-catalyzed cross-coupling. *Reagents and conditions*: (a) Bu_3SnOMe, Et_2O, r.t.; (b) (*E*)-$Bu_3SnCH{=}CHSnBu_3$ (1.1 equiv), [$PdCl_2(NCMe)_2$] (5%), DMF, r.t., 3–5 h; (c) I_2, Et_2O, r.t.; (d) sat. KF; (e) 0.1 M HCl.

Table 4 Yields of 5-Iodoalka-2,4-dienoic Acids Synthesized by Cross-Coupling of 3-Iodoalk-2-enoic Acids with (*E*)-1,2-Bis(tributylstannyl)ethene Followed by Iododestannylation

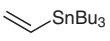
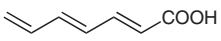
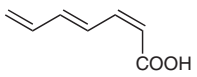
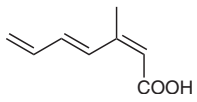
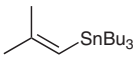
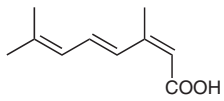
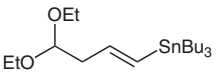
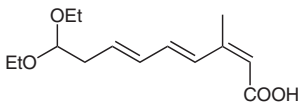
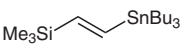
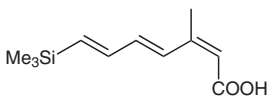
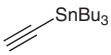
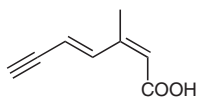
Entry	R^1	R^2	Starting material **3** or **5**	Product **8**	No	Yield[a] (%)
1	H	H	**3a**		**8a**	64
2	H	H	**5a**		**8b**	66
3	Me	H	**3b**		**8c**	70
4	Me	H	**5b**		**8d**	69
5	Me	D	**5i**		**8e**	74
6	Et	H	**3c**		**8f**	70
7	Pr	H	**3d**		**8g**	67
8	Pr	H	**5d**		**8h**	73
9	Me	H	**5b**		**8i**[b]	71

[a] Yield of Stille coupling with (*E*)-1,2-bis(tributylstannyl)ethene.
[b] Obtained when 0.5 equiv 1,2-bis(tributylstannyl)ethene was used.



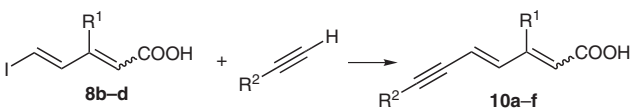
Scheme 8 Synthesis of trienoic acids by cross-coupling between iododienoic acids and vinylstannanes. *Reagents and conditions*: stannane (1.2 equiv), $[PdCl_2(NCMe)_2]$ (5%), DMF, r.t., 3 h.

Table 5 Yields of Trienoic Acids Synthesized by Cross-Coupling of Dienoic Acids with Vinyl- and Ethynylstannanes

Entry	Dienoic acid	Stannane	Product **9**	No	Yield (%)
1	**8a**			**9a**	88
2	**8b**			**9b**	84
3	**8d**			**9c**	96
4	**8d**			**9d**	74
5	**8d**			**9e**	72
6	**8d**			**9f**	86
7	**8d**			**9g**	79

Cross-Coupling with Alkynes

We also investigated the synthesis of dienynoic acids **10** (Scheme 9) from alkynes and iodoalkadienoic acids **8** under Sonogashira conditions,[37] using dichlorobis(triphenylphosphine)palladium(II), copper(I) iodide, butylamine, and *N*,*N*-dimethylformamide as solvent at room temperature. We thus obtained the corresponding dienynoic acids **10** in fair yields (Table 6).[38] In all cases, Glaser coupling (<5%) resulted in lower product yields. Protection of the carboxy function was not necessary, and the configurations of the two double bonds were unchanged. In addition, no cyclization to butenolides or α-pyrones occurred.[39]



Scheme 9 Synthesis of dienynoic acids from alkynes and iodoalkadienoic acids. *Reagents and conditions*: alkyne (1.5 equiv), $[PdCl_2(PPh_3)_2]$ (3%), CuI, $BuNH_2$, DMF, r.t., 4 h.

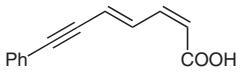
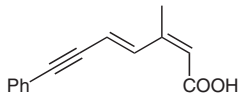
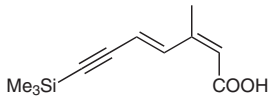
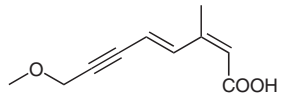
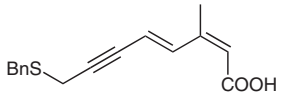
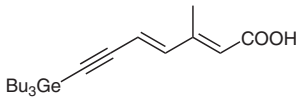
Application to Retinoid Synthesis

In view of the results we obtained in the synthesis of trienoic and dienynoic acids, we planned to apply this strategy to the synthesis of retinoic acids and some analogues. For this, fragments **B** and **C** needed to be synthesized (Scheme 1).

The synthesis of fragment **B** (**12a–c**) or **C** (**13**,**14**) began with β-ionone (**11a**), α-ionone (**11b**) (Scheme 10), or safranal (Scheme 11). Ionones **11a** and **11b** gave dienynes **12a** and **12b** in 80% yield (after distillation) by the reliable Negishi procedure (Scheme 10).[40] Trienyne **12c** was obtained from safranal by a method described by Wright for the synthesis of conjugated en-1-ynes (Scheme 11).[41]

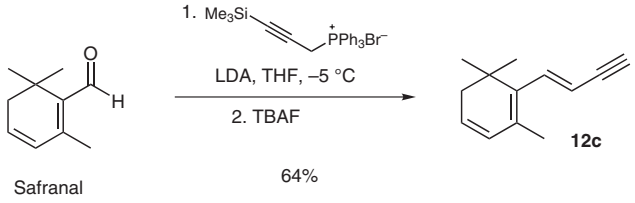
Treatment of dienynes **12** with 1.1 equivalents of the Lipshutz reagent $[(Bu_3Sn)(Bu)CuLi{\cdot}LiCN]$ at –78 °C in the presence of methanol (110 equiv) yielded (1*E*,3*E*)-dienylstannanes **13** mixed with internal vinylstannanes **15a** (**13**/**15a**, 75:25) (Scheme 10). Fortunately, we found that this ratio could be increased to 92:8 if the reaction was performed at –90 °C, if the intermediate vinylcuprate was trapped with an excess of methyl iodide (10 equiv) in the presence of tetrahydrofuran. In this case, the reaction oc-

Table 6 Yields of Dienynoic Acids Synthesized by Cross-Coupling of Dienoic Acids with Alkynes

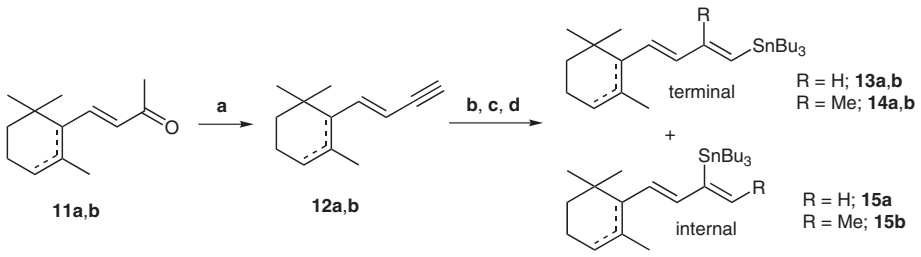
Entry	Dienoic acids	R^1	R^2	Product **10**	No	Yield (%)
1	**8b**	H	Ph		**10a**	75
2	**8d**	Me	Ph		**10b**	75
3	**8d**	Me	TMS		**10c**[38]	77
4	**8d**	Me	MOM		**10d**	70
5	**8d**	Me	CH_2SBn		**10e**	76
6	**8c**	Me	$GeBu_3$		**10f**[38]	72

curred in high regioselectivity, up to 92:8 in favor of the terminal dienylstannane **14** (**14/15b**, 92:8) (Scheme 10).

Iododestannylation of **13** or **14** with iodine in diethyl ether at low temperature quantitatively provided the corresponding vinyl iodides, but these were unfortunately very unstable and decomposed completely during purification by column chromatography. We therefore chose to use vinylstannane reagents **14** rather than vinyl iodides for the final stage of the synthesis. It should be noted that these vinylstannanes were used without any purification. Stille coupling of 5-iodoalka-2,4-dienoic acids **8** with vinylstannanes **14** in the presence of a catalytic amount (3%) of bis(acetonitrile)dichloropalladium(II) stereoselectively provided retinoids **16** in good to moderate yields (Scheme 12, Table 7). Cross-coupling occurred with retention of the configurations of the double bonds and no decomposition products were observed. Synthesis of all-*trans*-retinoic acid (**16c**) was also subsequently attempted from stannane **14a** and dienoic acid **8c**, with tetrakis(triphenylphosphine)palladium as catalyst; this gave all-*trans*-retinoic acid (**16c**) in poor yield, as already described by Negishi.[16a]

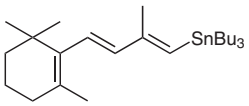
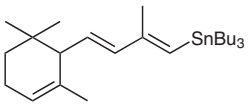


Scheme 11 Synthesis of a conjugated trienyne from safranal and an alkyne

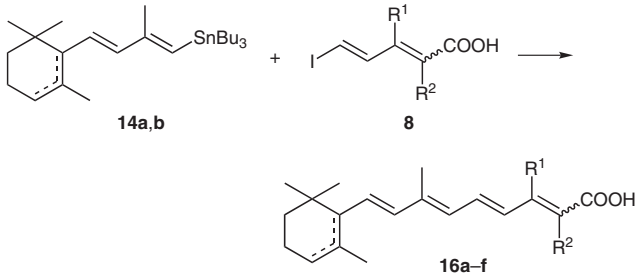


Scheme 10 Synthesis of vinyl stannanes from α- and β-ionones. *Reagents and conditions*: **13a**,**b** (R = H): (a) Negishi's conditions: LDA, –78 °C, 1 h, then $(EtO)_2POCl$, –78 °C, 1 h, then LDA, –78 °C to –20 °C, 3 h, then HCl; (b) $(Bu_3Sn)(Bu)CuLi{\cdot}LiCN$, THF, MeOH, –90 °C; (c) sat. NH_4Cl. **14a**,**b** (R = Me): (a) Negishi's conditions; (b) $(Bu_3Sn)(Bu)CuLi{\cdot}LiCN$, THF, MeOH, –90 °C; (c) MeI (10 equiv), –90 °C to 25 °C, 12 h; (d) sat. NH_4Cl.

Table 7 Yields of Retinoid Acids Synthesized by Cross-Coupling of Dienoic Acids with Vinylstannanes

Entry	Dienoic acids **8**	R^1	R^2	Vinylstannanes **14**	Product **16**	Yield[a] (%)
1	**8a**	H	H	 **14a**	**16a**	55
2	**8d**	Me	H	**14a**	**16b**	70
3	**8c**	Me	H	**14a**	**16c**	73
4	**8b**	H	H	**14a**	**16d**	45
5	**8d**	Me	H	 **14b**	**16e**	55

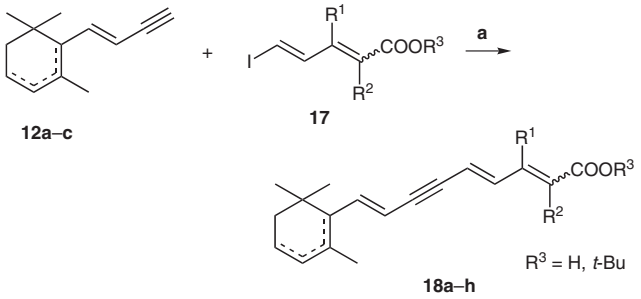
[a] Yields after purification.



Scheme 12 Synthesis of retinoid acids. *Reagents and conditions*: $[PdCl_2(NCMe)_2]$ (3%), DMF, 25 °C, 3 h.

It is interesting that if a mixture of a vinylstannane **14** and its positional isomer **15b** was used, only the terminal regioisomer **14** led to the desired coupling product.

Cross-coupling of enynes **12a–c** with iododienes **17** under the same conditions as described before (cf. Scheme 9) yielded didehydro retinoid acids **18** (Scheme 13, Table 8).



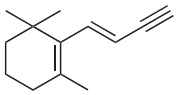
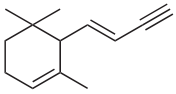
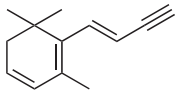
Scheme 13 Synthesis of didehydro retinoid acids by cross-coupling of enynes with iododienes. *Reagents and conditions*: $[PdCl_2(PPh_3)_2]$ (3%), CuI (3%), $BuNH_2$, DMF, r.t., 4–5 h.

Conclusion

We have investigated a new general route to both (*Z*,*E*,*E*)- and (*E*,*E*,*E*)-conjugated trienoic acids and describe a new stereoselective approach to the synthesis of retinoids, starting from inexpensive materials and based on cross-coupling reactions (Stille or Sonogashira reaction). In contrast to the most frequently reported methods, the method described here uses unprotected acids, thus saving protection and deprotection steps.

^{1}H NMR spectra were recorded at 200 MHz or at 300 MHz on Bruker AC200 and Bruker Avance DPX 300 spectrometers with $CDCl_3$ used as solvent. The residual proton resonance of $CDCl_3$ (δ_H = 7.25 ppm) was used as the internal reference. ^{13}C NMR spectra were recorded at 50 MHz or 75 MHz on the same spectrometers with $CDCl_3$ used as solvent; the solvent peak at δ_C = 77.0 ppm was used as the reference. EI mass spectra were measured at 70 eV by GC-MS or direct introduction mode. The isotopic patterns are given for ^{120}Sn (isotopic values 33%) in organotin fragments; this means that the reported values (values in brackets) for organotin fragments were only roughly one third of the correct value, taking into account the 10 isotopes of tin compared with those of organic fragments. Melting points are uncorrected. Standard column chromatography was performed on Merck silica gel (60 Å, 230–400 mesh silica gel) by flash column chromatography techniques. Analytical TLC was conducted on Merck precoated silica gel 60 F_{254} plates. All reactions were performed in oven-dried glassware under positive argon pressure, unless otherwise noted. Reaction mixtures were stirred magnetically. Et_2O was dried and freshly distilled from sodium/benzophenone. DMF was dried by distillation over CaH_2 prior to use. Acids **1a** and **1b** were prepared by a previously reported procedure.[42] 4-Methoxybut-3-ynoic acid (**1h**) was prepared by carbonation of 3-methoxypropynylmagnesium bromide. Other acids **1c–g** were purchased from commercial suppliers and used without purification. Tributyl(vinyl)stannane was prepared from vinylmagnesium bromide and bis(tributyltin) oxide.[43] (*E*)-1-(Tributylstannyl)-2-(trimethylsilyl)ethene was prepared by hydrostannation of (trimethylsilyl)acetylene.[44] (*E*)-Tributyl(β-styryl)stannane was prepared by hydrostannation of phenylacetylene.[45] (*E*)-4,4-Diethoxy-1-(tributylstannyl)but-1-ene was obtained by stannylmetalation of the

Table 8 Yields of 9,10-Didehydro Retinoid Acids Synthesized by Cross-Coupling of Enynes with Iododienes

Entry	Diene	R^1	R^2	R^3	Enyne	Product	Yield[a] (%)
1	**17a**	H	H	H	 **12a**	**18a**	70
2	**17b**	Me	H	H	**12a**	**18b**	80
3	**17c**	Me	D	H	**12a**	**18c**	73
4	**17d**	Et	H	H	**12a**	**18d**	76
5	**17e**	Me	H	*t*-Bu	**12a**	**18e**	78
6	**17b**	Me	H	H	 **12b**	**18f**	85
7	**17c**	Me	D	H	**12b**	**18g**	76
8	**17b**	Me	H	H	 **12c**	**18h**	72

[a] Yields after purification.

homopropargylic acetal by (tributylstannyl)(methyl)magnesium in the presence of CuCN.[46] (Tributylstannyl)acetylene was prepared from ethynyllithium–ethylenediamine complex and Bu_3SnCl[47]. Alkynes **12a** and **12b** were prepared by a method described by Negishi.[40]

Compounds 2 and 2′ by Stannylcupration of Alk-2-ynoic Acids 1; General Procedure

$(Bu_3Sn)(Bu)CuLi·LiCN$ was prepared by the general route outlined by Lipshutz.[48] CuCN (1.8 g, 20.17 mmol) was suspended in freshly distilled THF (60 mL), and the mixture was cooled at –78 °C and treated with 1.6 M BuLi in hexane (25.2 mL, 40.35 mmol). The mixture was allowed to react for 15 min, and then Bu_3SnH (10.85 mL, 40.35 mmol) was added dropwise. After the mixture had stirred for 10 min at –78 °C, the 3-substituted alk-2-ynoic acid **1** (8.77 mmol) diluted in THF (10 mL) was added, and the reaction was allowed to proceed for 1 h. The reaction mixture was quenched with sat. NH_4Cl soln at –78 °C and diluted with Et_2O. The organic layer was separated, washed with brine (30 mL), and dried over $MgSO_4$. After the solvent had been removed by rotary evaporation, purification of the residue by column chromatography (silica gel, PE–Et_2O, 50:50, then CH_2Cl_2) gave **2**.

(*E*)-3-(Tributylstannyl)acrylic Acid (2a)

Yield: 65%; yellow oil.

IR (neat): 1690, 1624, 1570 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.93 (t, *J* = 7.2 Hz, 9 H), 1.02 (m, 6 H), 1.23–1.62 (m, 12 H), 6.36 (d, *J* = 19.4 Hz, J_{Sn-H} = 54–51 Hz, 1 H), 7.93 (d, *J* = 19.4 Hz, J_{Sn-H} = 58 Hz, 1 H), 10.70 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.6 (J_{Sn-C} = 335–351 Hz, 3 C), 13.5, 27.1 (J_{Sn-C} = 57–55 Hz, 3 C), 28.8 (J_{Sn-C} = 21 Hz, 3 C), 135.6 (J_{Sn-C} = 13 Hz), 156.4 (J_{Sn-C} = 292–283 Hz), 169.6 (J_{Sn-C} = 69 Hz).

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –45.5.

MS (EI, 70 eV): *m*/*z* (%) = 305 (36) [M^+ – 57], 249 (57), 193 (48), 191 (48), 177 (11), 137 (21), 121 (21) [organotin fragments], 57 (23), 45 (10), 41 (100) [organic fragments].

(*E*)-3-(Tributylstannyl)but-2-enoic Acid (2b)

Yield: 63%; yellow oil.

IR (neat): 1689, 1597 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7.2 Hz, 9 H), 0.98 (m, 6 H), 1.30–1.78 (m, 12 H), 2.46 (d, *J* = 1.7 Hz, J_{Sn-H} = 44 Hz, 3 H), 6.05 (q, *J* = 1.7 Hz, J_{Sn-H} = 63 Hz, 1 H), 10.70 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.3 (J_{Sn-C} = 335–321 Hz, 3 C), 13.5, 22.5 (J_{Sn-C} = 26 Hz), 27.2 (J_{Sn-C} = 57 Hz, 3 C), 28.8 (J_{Sn-C} = 20 Hz, 3 C), 127.5 (J_{Sn-C} = 36 Hz), 169.8 (J_{Sn-C} = 77 Hz), 173.5 (J_{Sn-C} = 318 Hz).

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –32.6.

MS (EI, 70 eV): *m*/*z* (%) = 319 (43) [M^+ – 57], 263 (56), 207 (46), 177 (22), 137 (37), 121 (30) [organotin fragments], 85 (23), 69 (18), 67 (17), 55 (11), 41 (100), 39 (54) [organic fragments].

(*E*)-3-(Tributylstannyl)pent-2-enoic Acid (2c)

Yield: 68%; yellow oil.

IR (neat): 1686, 1628, 1180 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.87 (t, *J* = 7.1 Hz, 9 H), 0.94 (m, 6 H), 1.02 (t, *J* = 7.5 Hz, 3 H), 1.20–1.60 (m, 12 H), 2.87 (qd, *J* = 7.5, 1.1 Hz, J_{Sn-H} = 56 Hz, 2 H), 5.92 (t, *J* = 1.1 Hz, J_{Sn-H} = 65–62 Hz, 1 H), 10.75 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.9 (J_{Sn-C} = 334–319 Hz, 3 C), 13.5, 13.8 (J_{Sn-C} = 10.5 Hz), 27.2 (J_{Sn-C} = 58 Hz, 3 C), 28.5 (J_{Sn-C} = 25 Hz), 28.8 (J_{Sn-C} = 20 Hz, 3 C), 126.5 (J_{Sn-C} = 35.5 Hz), 169.6 (J_{Sn-C} = 82 Hz), 177 (J_{Sn-C} = 319 Hz).

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –33.6.

MS (EI, 70 eV): *m/z* (%) = 333 (100) [M$^+$ – 57], 277 (76), 221 (57), 219 (54), 137 (29), 121 (22) [organotin fragments], 99 (10), 81 (21), 41 (15) [organic fragments].

(*E*)-3-(Tributylstannyl)hex-2-enoic Acid (2d)
Yield: 64%; yellow oil.

IR (neat): 1690, 1595, 1240 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.86 (t, *J* = 7.2 Hz, 9 H), 0.92 (m, 9 H), 1.15–1.66 (m, 14 H), 2.84 (t, *J* = 7.1 Hz, J_{Sn-H} = 57 Hz, 2 H), 5.95 (t, *J* = 1 Hz, J_{Sn-H} = 65.8–63.4 Hz, 1 H), 9.80 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 10 (J_{Sn-C} = 318–333 Hz, 3 C), 13.5 (3 C), 14, 22.8 (J_{Sn-C} = 10 Hz), 27.2 (J_{Sn-C} = 55.5–58.7 Hz, 3 C), 28.8 (J_{Sn-C} = 20 Hz, 3 C), 37.2 (J_{Sn-C} = 24.3 Hz), 127 (J_{Sn-C} = 35 Hz), 169.8 (J_{Sn-C} = 80.5–83.8 Hz), 177.5 (J_{Sn-C} = 309.5–324.2 Hz).

MS (EI, 70 eV): *m/z* (%) = 347 [M$^+$ – 57] (100), 291 (50), 235 (49), 177 (26), 137 (20), 121 (15) [organotin fragments], 95 (21), 57 (10), 41 (17) [organic fragments].

(*E*)-3-(Tributylstannyl)oct-2-enoic Acid (2e)
Yield: 72%; yellow oil.

IR (neat): 3400–2500, 1690, 1595, 1240 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.87 (t, *J* = 7.1 Hz, 9 H), 0.95 (m, 9 H), 1.20–1.62 (m, 18 H), 2.85 (br t, *J* = 7.4 Hz, J_{Sn-H} = 57 Hz, 2 H), 5.94 (br s, J_{Sn-H} = 66–63.6 Hz, 1 H), 11.90 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 10 (J_{Sn-C} = 333.3–318.4 Hz, 3 C), 13.4 (3 C), 13.8, 22.3, 27.2 (J_{Sn-C} = 50–51 Hz, 3 C), 28.8 (J_{Sn-C} = 20 Hz, 3 C), 29.1 (J_{Sn-C} = 10 Hz), 31.7, 35.3 (J_{Sn-C} = 24 Hz), 127 (J_{Sn-C} = 34 Hz), 169.7 (J_{Sn-C} = 83 Hz), 178.2 (J_{Sn-C} = 342–320 Hz).

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –34.0.

MS (EI, 70 eV): *m/z* (%) = 375 (100) [M$^+$ – 57], 319 (33), 263 (28), 177 (27), 137 (21), 121 (15) [organotin fragments], 95 (19), 81 (13), 55 (11), 41 (18) [organic fragments].

(*E*)-3-Phenyl-3-(tributylstannyl)acrylic Acid (2f)
Yield: 62%; yellow oil.

IR (neat): 3076, 3059, 3018, 1695, 1604 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.92 (t, *J* = 7.2 Hz, 9 H), 0.95 (m, 6 H), 1.24–1.69 (m, 12 H), 6.17 (s, J_{Sn-H} = 58–56 Hz, 1 H), 6.94–7.01 (m, 2 H, Ar), 7.15–7.36 (m, 3 H, Ar), 11.20 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 10.2 (J_{Sn-C} = 335–321 Hz, 3 C), 13.5 (3 C), 27.1 (J_{Sn-C} = 59–56 Hz, 3 C), 28.7 (J_{Sn-C} = 20.5 Hz, 3 C), 124.4 (J_{Sn-C} = 60 Hz, 2 C), 125.9, 127.4 (J_{Sn-C} = 35 Hz), 128 (2 C), 144 (J_{Sn-C} = 18 Hz), 170 (J_{Sn-C} = 68.9 Hz), 173.1 (J_{Sn-C} = 290 Hz).

MS (EI, 70 eV): *m/z* (%) = 381 (12) [M$^+$ – 57], 269 (100), 267 (74), 213 (45), 177 (28), 155 (33) [organotin fragments], 147 (76), 103 (39), 102 (19), 91 (24), 77 (37), 57 (39), 51 (33), 41 (56), 39 (26) [organic fragments].

(*E*)-3-(Tributylstannyl)-3-(trimethylsilyl)acrylic Acid (2g)
Yield: 55%; yellow oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.13 (s, 9 H), 0.95 (t, *J* = 7.2 Hz, 9 H), 0.96–1.05 (m, 6 H), 1.23–1.63 (m, 12 H), 8.23 (s, J_{Sn-H} = 70 Hz, 1 H), 10.7 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –1.4 (3 C), 9.6 (J_{Sn-C} = 334–352 Hz, 3 C), 13.4 (3 C), 27.2 (J_{Sn-C} = 57–55 Hz, 3 C), 29 (J_{Sn-C} = 21 Hz, 3 C), 138.2 (J_{Sn-C} = 13 Hz), 164.2 (J_{Sn-C} = 293–284 Hz), 169.8 (J_{Sn-C} = 67 Hz).

(*E*)-4-Methoxy-3-(tributylstannyl)but-2-enoic Acid (2h)
Yield: 72%; yellow oil.

IR (neat): 1685, 1600, 1235, 1110 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.87 (t, *J* = 7.2 Hz, 9 H), 0.86–0.96 (m, 6 H), 1.23–1.51 (m, 12 H), 3.35 (s, 3 H), 4.54 (d, *J* = 2.7 Hz, J_{Sn-H} = 29–24 Hz, 2 H), 5.93 (t, *J* = 2.7 Hz, J_{Sn-H} = 59 Hz, 1 H), 10.8 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 10.8 (J_{Sn-C} = 335–351 Hz, 3 C), 13.6 (3 C), 27.1 (J_{Sn-C} = 59 Hz, 3 C), 29 (J_{Sn-C} = 20 Hz, 3 C), 58, 76.3 (J_{Sn-C} = 21 Hz), 123.2 (J_{Sn-C} = 26 Hz), 169.6 (J_{Sn-C} = 74 Hz), 181 (J_{Sn-C} = 322 Hz).

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –33.3.

MS (EI, 70 eV): *m/z* (%) = 349 (45) [M$^+$ – 57], 317 (100), 273 (19), 261 (17), 235 (17), 203 (15), 177 (52), 121 (19) [organotin fragments], 57 (25), 55 (13), 43 (12), 41 (72), 39 (38) [organic fragments].

(*E*)-3-(Tributylstannyl)[2-^{2}H]but-2-enoic Acid (2i)
Yield: 60%; yellow oil.

IR (neat): 2238, 1689, 1598 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7.2 Hz, 9 H), 0.95–0.98 (m, 6 H), 1.30–1.78 (m, 12 H), 2.22 (s, J_{Sn-H} = 38 Hz, 3 H), 10.35 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.3 (J_{Sn-C} = 335–321 Hz, 3 C), 13.4 (3 C), 22.5 (J_{Sn-C} = 25 Hz), 27.2 (J_{Sn-C} = 58 Hz, 3 C), 28.8 (J_{Sn-C} = 21 Hz, 3 C), 124.2 (t, J_{C-D} = 26 Hz), 169.8 (J_{Sn-C} = 76 Hz), 173.5 (J_{Sn-C} = 318 Hz).

MS (EI, 70 eV): *m/z* (%) = 320 (43) [M$^+$ – 57], 264 (56), 208 (46), 177 (21), 137 (37), 121 (23) [organotin fragments], 57 (14), 55 (14), 43 (26), 41 (100), 39 (37) [organic fragments].

(*Z*)-2-Iodo-3-(tributylstannyl)but-2-enoic Acid (2j)
Yield: 45%; yellow oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7.1 Hz, 9 H), 0.92–0.95 (m, 6 H), 1.24–1.69 (m, 12 H), 2.23 (s, J_{Sn-H} = 38 Hz, 3 H), 11.3 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 11.9 (J_{Sn-C} = 342–327 Hz, 3 C), 13.5 (3 C), 25.1 (J_{Sn-C} = 20.4 Hz), 27.2 (J_{Sn-C} = 60 Hz, 3 C), 28.7 (J_{Sn-C} = 20 Hz, 3 C), 93.1 (J_{Sn-C} = 23 Hz), 168.6 (J_{Sn-C} = 72 Hz), 172.6 (J_{Sn-C} = 278 Hz).

Tributylstannyl (*E*)-3-(Tributylstannyl)but-2-enoate (2b′)
Yield: 76%; yellow oil.

IR (neat): 1599, 1543, 1525 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.89–1.66 (m, 54 H), 2.37 (d, *J* = 1.8 Hz, J_{Sn-H} = 47 Hz, 3 H), 6.06 (q, *J* = 1.8 Hz, J_{Sn-H} = 66 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.2 (J_{Sn-C} = 333–317 Hz, 3 C), 13.5 (6 C), 16.3 (J_{Sn-C} = 361–344 Hz, 3 C), 22.0 (J_{Sn-C} = 30 Hz), 26.9 (J_{Sn-C} = 67–63 Hz, 3 C), 27.2 (J_{Sn-C} =& nbsp;58–55 Hz, 3 C), 27.8 (J_{Sn-C} = 20 Hz, 3 C), 28.9 (J_{Sn-C} = 20 Hz, 3 C), 130.1 (J_{Sn-C} = 32 Hz), 164.1 (J_{Sn-C} = 348–333 Hz), 170.3 (J_{Sn-C} = 79 Hz).

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –35.5, 100.1.

MS (EI, 70 eV): *m/z* (%) = 609 (29) [M$^+$ – 57], 319 (16), 317 (13), 291 (14), 247 (16), 235 (31), 177 (49) [organotin fragments], 57 (45), 42 (14), 41 (100), 39 (42) [organic fragments].

Tributylstannyl (*E*)-3-Phenyl-3-(tributylstannyl)acrylate (2f′)
Yield: 73%; white crystals; mp 56–58 °C.

IR (neat): 3076, 3059, 1695, 1604, 1234, 908 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.85–1.70 (m, 54 H), 6.15 (s, J_{Sn-H} = 59–56 Hz, 1 H), 6.94–7.02 (m, 2 H, Ar), 7.15–7.36 (m, 3 H, Ar).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 10.2 (J_{Sn-C} = 335–321 Hz, 3 C), 13.5 (6 C), 17.4 (J_{Sn-C} = 337–322 Hz, 3 C), 26.8 (J_{Sn-C} = 65–61 Hz, 3 C), 27.1 (J_{Sn-C} = 59–56 Hz, 3 C), 27.7 (J_{Sn-C} = 24–22 Hz, 3 C), 28.7 (J_{Sn-C} = 20.5 Hz, 3 C), 124.4 (J_{Sn-C} = 60 Hz, 2 C), 125.9, 127.4 (J_{Sn-C} = 35 Hz), 127.9 (2 C), 144 (J_{Sn-C} = 18 Hz), 168 (J_{Sn-C} = 69 Hz), 172 (J_{Sn-C} = 290 Hz).

MS (EI, 70 eV): *m*/*z* (%) = 669 (5) [M^+ – 57], 381 (100), 267(18), 177 (28), 121 (10) [organotin fragments], 147 (12), 137 (19), 77 (12), 69 (16), 41 (16) [organic fragments].

3-Iodoalk-2-enoic Acids 3 by Iododestannylation of Acids 2; General Procedure

Vinylstannane **2** (12 mmol) in freshly distilled Et_2O (30 mL) was cooled to 0 °C and treated with a soln of I_2 (3.5 g, 14 mmol) in Et_2O (30 mL). The mixture was allowed to react for 2 h at r.t., and then washed with 0.5 M $Na_2S_2O_3$ (20 mL) to eliminate excess I_2. The mixture was then hydrolyzed with sat. aq KF (25 mL) and acetone (25 mL) to remove all the tributyltin salts that had formed. After vigorous stirring for 3 h, the reaction mixture was filtered and washed with H_2O (2 × 15 mL). The aqueous layer was acidified with 1 M HCl soln and extracted with Et_2O (3 × 25 mL), and the organic soln was washed with brine (2 × 15 mL). After usual treatment, the crude acid **3** was purified by crystallization (PE–Et_2O, 90:10).

(*E*)-3-Iodopent-2-enoic Acid (3c)

Yield: 60%; colorless oil.

IR (neat): 3068, 2921, 2851, 2712, 2617, 1692, 1608, 1237 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.18 (t, *J* = 7.4 Hz, 3 H), 3.17 (qd, *J* = 7.4, 0.7 Hz, 2 H), 6.68 (t, *J* = 0.7 Hz, 1 H), 11 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 14.3, 35.5, 130, 135.4, 168.7.

MS (EI, 70 eV): *m*/*z* (%) = 226 [M^+] (1), 127 (6), 99 (100), 71 (16), 53 (41), 45 (11), 43 (61).

(*E*)-3-Iodohex-2-enoic Acid (3d)

Yield: 57%; colorless oil.

IR (neat): 3067, 2964, 2932, 2729, 2617, 1697, 1604, 1248 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.00 (t, *J* = 7.3 Hz, 3 H), 1.66 (sext, *J* = 7.3 Hz, 2 H), 3.14 (t, *J* = 7.3 Hz, 2 H), 6.74 (s, 1 H), 11.8 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 12.7, 23, 43, 130.7, 133.9, 169.3.

MS (EI, 70 eV): *m*/*z* (%) = 240 (1) [M^+], 113 (100), 95 (27), 69 (14), 67 (38), 45 (23), 43 (34), 41 (74), 39 (60).

(*E*)-3-Iodo-3-phenylacrylic Acid (3f)

Yield: 59%; white crystals; mp 184–186 °C.

IR (KBr): 3077, 2954, 2818, 1691, 1616, 1587, 1150 cm^{-1}.

^{1}H NMR (200 MHz, acetone-d_6): δ = 6.88 (s, 1 H), 7.34 (br s, 5 H, Ar), 10.48 (br s, 1 H).

^{13}C NMR (50 MHz, acetone-d_6): δ = 116.2, 127.5 (2 C), 127.7, 128.8 (2 C), 132.7, 142.5, 163.6.

MS (EI, 70 eV): *m*/*z* (%) = 274 (1) [M^+], 103 (24), 102 (100), 77 (12), 51 (11), 44 (38).

(*E*)-3-Iodo-3-(trimethylsilyl)acrylic Acid (3g)

Yield: 51%; pale yellow crystals; mp 103–105 °C.

IR (KBr): 3077, 2783, 2573, 1698, 1587, 1207 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.30 (s, 9 H), 7.04 (s, 1 H), 10.50 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –1.67 (3 C), 130, 133.8, 169.1.

MS (EI, 70 eV): *m*/*z* (%) = 270 (29) [M^+], 255 (28), 185 (23), 127 (16), 75 (100), 73 (63), 45 (46), 44 (12), 43 (77).

(*E*)-3-Iodo-4-methoxybut-2-enoic Acid (3h)

Yield: 63%; colorless oil.

IR (neat): 3084, 1689, 1604, 1242, 1114 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.41 (s, 3 H), 4.58 (d, *J* = 1.6 Hz, 2 H), 6.92 (t, *J* = 1.6 Hz, 1 H), 10.5 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 58.0, 73, 130.6, 131.8, 168.5.

MS (EI, 70 eV): *m*/*z* (%) = 242 (2) [M^+], 115 (100), 87 (24), 69 (26), 45 (31), 39 (49).

(*E*)-3-Iodo[2-^{2}H]but-2-enoic Acid (3i)

Yield: 58%; white crystals; mp 71–73 °C.

IR (KBr): 2287, 1674, 1601, 1263 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.04 (s, 3 H), 10 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 32, 124.5, 131.4 (t, J_{C-D} = 25 Hz), 169.6.

MS (EI, 70 eV): *m*/*z* (%) = 213 (8) [M^+], 127 (14), 86 (100), 45 (26), 43 (41), 41 (34), 40 (99), 39 (93).

(*Z*)-2,3-Diiodobut-2-enoic Acid (3j)

Yield: 38%; white crystals; mp 71–73 °C.

IR (neat): 3043, 2955, 2801, 2620, 1676, 1559, 1264, 1086 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.00 (s, 3 H), 7.00 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 33.6, 98, 127.3, 169.

MS (EI, 70 eV): *m*/*z* (%) = 338 (7) [M^+], 254 (16), 211 (42), 127 (18), 45 (10), 39 (100), 38 (32).

Alka-2,4-dienoic Acids 4 by Cross-Coupling of Acids 3 with Vinylstannanes; General Procedure

$[PdCl_2(NCMe)_2]$ (129 mg, 0.5 mmol) was added to a DMF soln (15 mL) of acid **3** (10 mmol) and the appropriate vinylstannane (12 mmol) in a 50-mL flask. The mixture was stirred for 6 h at 25 °C, then hydrolyzed with a 1 M soln of KF (25 mL) and acetone (25 mL) to precipitate the Bu_3SnI that had formed. After strongly stirring for 2 h, the reaction mixture was filtered, washed with a 0.1 M HCl soln (2 × 15 mL) and extracted with Et_2O (3 × 20 mL). After usual workup, the crude acid **4** was purified by crystallization (PE–Et_2O, 95:5).

(*E*)-3-Ethylpenta-2,4-dienoic Acid (4d)

Yield: 77%; colorless oil.

IR (neat): 3094, 1687, 1626, 1601, 1284, 1236 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.15 (t, *J* = 7.5 Hz, 3 H), 2.85 (q, *J* = 7.5 Hz, 2 H), 5.47 (d, *J* = 10.8 Hz, 1 H), 5.73 (d, *J* = 17.4 Hz, 1 H), 5.80 (s, 1 H), 6.38 (dd, *J* = 10.8, 17.4 Hz, 1 H), 10.65 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 14, 20.4, 118.1, 120, 138.4, 160.5, 172.

MS (EI, 70 eV): *m*/*z* (%) = 126 (95) [M^+], 125 (41), 111 (67), 97 (54), 83 (30), 69 (35), 55 (58), 53 (77), 45 (30), 43 (54), 41 (75), 39 (100), 38 (15).

(2*E*,4*E*)-3-Ethyl-5-(trimethylsilyl)penta-2,4-dienoic Acid (4e)

Yield: 82%; yellow crystals; mp 57–59 °C.

IR (KBr): 3072, 1689, 1612, 1576, 1286, 1248 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.16 (9 H, s), 1.12 (t, *J* = 7.5 Hz, 3 H), 2.85 (q, *J* = 7.5 Hz, 2 H), 5.81 (s, 1 H), 6.44 (d, *J* = 19.2 Hz, 1 H), 6.54 (d, *J* = 19.2 Hz, 1 H), 10.40 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –1.6 ($J_{Si–C}$ = 53 Hz, 3 C), 14, 20.3, 118.3, 137.2 ($J_{Si–C}$ = 63 Hz), 144.8, 161.2, 172.3.

MS (EI, 70 eV): *m*/*z* (%) = 198 (5) [M$^+$], 183 (23), 169 (9), 125 (98), 75 (100), 73 (31), 59 (24), 45 (30), 43 (21).

(2*E*,4*E*)-3-Ethyl-5-phenylpenta-2,4-dienoic Acid (4f)
Yield: 84%; colorless oil.

IR (neat): 3450, 3086, 3032, 1684, 1599, 1240 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.24 (t, *J* = 7.5 Hz, 3 H), 3.00 (q, *J* = 7.5 Hz, 2 H), 5.93 (s, 1 H), 6.79 (d, *J* = 16.2 Hz, 1 H), 7.34 (d, *J* = 16.2 Hz, 1 H), 7.35–7.46 (m, 3 H, Ar), 7.51–7.56 (m, 2 H, Ar), 8.90 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 14.1, 20.9, 117.8, 127 (2 C), 128.7 (3 C), 130.1, 134.5, 136.2, 161.0, 171.7.

MS (EI, 70 eV): *m*/*z* (%) = 202 (14) [M$^+$], 157 (39), 141 (29), 129 (100), 128 (39), 115 (32), 78 (15), 77 (33), 51 (32), 45 (11), 39 (27).

(2*E*,4*E*)-7,7-Diethoxy-3-ethylhepta-2,4-dienoic Acid (4g)
Yield: 62%; pale yellow crystals; mp 49–51 °C.

IR (KBr): 3086, 3030, 1685, 1637, 1599, 1236 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.14 (t, *J* = 7.5 Hz, 3 H), 1.25 (t, *J* = 7.0 Hz, 6 H), 2.56 (br t, *J* = 5.7 Hz, 2 H), 2.85 (q, *J* = 7.5 Hz, 2 H), 3.56 (dq, *J* = 9.3, 7.0 Hz, 2 H), 3.71 (dq, *J* = 9.3, 7.0 Hz, 2 H), 4.59 (t, *J* = 5.6 Hz, 1 H), 5.72 (s, 1 H), 6.12 (d, *J* = 15.8 Hz, 1 H), 6.20 (dt, *J* = 15.8, 5.6 Hz, 1 H), 10.4 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 14.0, 15.2 (2 C), 20.9, 37.7, 61.4 (2 C), 102, 116.3, 132.1, 134.2, 161, 171.1.

MS (EI, 70 eV): *m*/*z* (%) = 197 (3) [M$^+$ – 45], 103 (59), 79 (15), 77 (11), 75 (68), 47 (100), 43 (12).

(*Z*)-3-(Trimethylsilyl)penta-2,4-dienoic Acid (4h)
Yield: 76%; yellow oil.

IR (neat): 3080–2570, 1688, 1620, 1170 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.28 (s, 9 H), 5.47 (m, *J* = 11.1 Hz, 1 H), 5.53 (m, *J* = 18 Hz, 1 H), 6.07 (d, *J* = 1.2 Hz, 1 H), 7.62 (ddd, *J* = 18, 11.2, 1.2 Hz, 1 H), 9.80 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –0.68 (3 C), 121.8, 126, 135.6, 161.7, 170.8.

MS (EI, 70 eV): *m*/*z* (%) = 170 (20) [M$^+$], 155 (26), 111 (48), 75 (83), 73 (100), 52 (55), 45 (49), 43 (29).

(2*Z*,4*E*)-3,5-Bis(trimethylsilyl)penta-2,4-dienoic Acid (4i)
Yield: 75%; yellow oil.

IR (neat): 3075–2560, 1684, 1627, 1180 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.16 (s, 9 H), 0.26 (s, 9 H), 6.05 (dd, *J* = 1.2, 0.5 Hz, 1 H), 6.17 (dd, *J* = 19.6, 0.5 Hz, 1 H), 7.74 (dd, *J* = 19.6, 1.2 Hz, 1 H), 9.50 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –1.62 ($J_{Si–C}$ = 52 Hz, 3 C), –0.62 ($J_{Si–C}$ = 51 Hz, 3 C), 125.2, 139.1, 142.7, 163.5, 170.5.

MS (EI, 70 eV): *m*/*z* (%) = 242 (3) [M$^+$], 169 (100), 152 (17), 133 (15), 75 (35), 73 (79), 45 (43).

(2*E*,4*E*)-5-(Trimethylsilyl)penta-2,4-dienoic Acid (4j)
Yield: 82%; yellow oil.

IR (neat): 3425–2553, 1687, 1624, 1575, 1246, 1016 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.16 (s, 9 H), 5.92 (d, *J* = 15.3 Hz, 1 H), 6.45 (d, *J* = 18.3 Hz, 1 H), 6.68 (dd, *J* = 18.3, 10.1 Hz, 1 H), 7.35 (dd, *J* = 15.3, 10.1 Hz, 1 H), 8.0 (1 H, s).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –1.8, 120.5, 140.8, 146.6, 148.4, 172.3.

MS (EI, 70 eV): *m*/*z* (%) = 87 (10), 71 (100), 57 (18), 45 (10), 43 (63), 39 (25).

6-[(*Z*)-2-Carboxy-1-(methoxymethyl)vinyl]-2-(methoxymethyl)cyclohex-2-ene-1-carboxylic Acid (4k)
Yield: 80%; colorless oil.

IR (neat): 1709, 1687, 1633, 1322, 1257, 1087 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.62 (m, 1 H), 2.15–2.34 (m, 3 H), 3.07–3.13 (m, 1 H), 3.28–3.33 (m, 3 H), 3.37–3.40 (m, 3 H), 3.56 (d, *J* = 5.3 Hz, 1 H), 3.90 (s, 1 H), 4.48 (d, *J* = 15.3 Hz, 1 H), 4.91 (d, *J* = 15.8 Hz, 1 H), 5.73 (s, 1 H), 6.03 (br s, 1 H), 10.2 (br s, 2 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 20.9, 24.9, 38.5, 45.5, 57.5, 58.5, 70.1, 75.9, 115.8, 128.9, 131, 163.2, 170.8, 178.1.

MS (EI, 70 eV): *m*/*z* (%) = 179 (13), 131 (14), 129 (16), 115 (17), 93 (14), 91 (50), 77 (19), 69 (10), 67 (10), 65 (16), 55 (18), 53 (19), 45 (100), 44 (19), 43 (23), 41 (35), 39 (30).

Alk-2-enoic Acids 6 by Cross-Coupling of Organohalides with Alk-2-enoates 2a′ or 2b′
These reactions were performed according to a previously reported method.[32]

(2*E*,4*E*)-5-Chloropenta-2,4-dienoic Acid (6a)
Yield: 62%; colorless oil.

IR (neat): 3140, 3070, 1680, 1625, 1160 cm^{-1}.

^{1}H NMR (200 MHz, acetone-d_6): δ = 6.05 (d, *J* = 15.3 Hz, 1 H), 6.80 (dd, *J* = 13.0, 11.2 Hz, 1 H), 7.01 (d, *J* = 13.0 Hz, 1 H), 7.33 (dd, *J* = 15.3, 11.2 Hz, 1 H), 9.50 (br s, 1 H).

^{13}C NMR (50 MHz, acetone-d_6): δ = 122.4, 128.8, 131.8, 140.2, 166.8.

MS (EI, 70 eV): *m*/*z* (%) = 132 (19) [M$^+$], 97 (100), 87 (16), 79 (91), 69 (33), 61 (33).

(*E*)-3-(*p*-Tolylsulfonyl)but-2-enoic Acid (6b)
Yield: 68%; yellow crystals; mp 87–89 °C.

IR (KBr): 3200–2600, 1675, 1620, 1600, 1145 cm^{-1}.

^{1}H NMR (200 MHz, acetone-d_6): δ = 2.24 (s, 3 H), 2.42 (s, 3 H), 6.90 (s, 1 H), 7.34 (d, *J* = 8 Hz, 2 H), 7.73 (d, *J* = 8 Hz, 2 H), 9.2 (br s, 1 H).

^{13}C NMR (50 MHz, acetone-d_6): δ = 17.5, 25.8, 130.4, 133.7 (2 C), 135.3 (2 C), 139.9, 150.5, 158.8, 169.8.

(2*E*,4*E*,6*E*)-Octa-2,4,6-trienedioic Acid (6c)
Yield: 75%; yellow crystals; mp 110–112 °C.

IR (KBr): 3400–2500, 1698, 1670, 1623, 1012 cm^{-1}.

^{1}H NMR (200 MHz, DMSO-d_6): δ = 6.08 (d, *J* = 8 Hz, 2 H), 6.87 (dd, *J* = 8, 2.2 Hz, 2 H), 7.27 (ddd, *J* = 15, 8, 2.2 Hz, 2 H), 12.5 (br s, 2 H)

^{13}C NMR (50 MHz, DMSO-d_6): δ = 126.4 (2 C), 138.1 (2 C), 143.8 (2 C) 168.3 (2 C).

MS (EI, 70 eV): *m*/*z* (%) = 168 (50) [M$^+$], 122 (100), 94 (49), 79 (49), 77 (89), 66 (58), 55 (57), 51 (83), 45 (68), 41 (79).

Alka-2,4-dienoates 7 by Cross-Coupling of Acids 3 or 5 with (*E*)-1,2-Bis(tributylstannyl)ethene; General Procedure
A dry 250-mL two-necked flask, flushed with argon, was charged with a soln of the tributyltin iodocarboxylate derivative of **3** or **5** (10 mmol) in DMF (50 mL) and [$PdCl_2(NCMe)_2$] (52 mg, 2 mol%). When the soln had become pale yellow, it was cooled to 0 °C, and (*E*)-1,2-bis(tributylstannyl)ethene (7.27 g, 12 mmol) was added. When the reaction had reached completion (after stirring at 25 °C for 6 h, the soln had become dark, and the end of the reaction was

checked by ^{1}H NMR spectroscopy), a 0.5 M soln of KF (30 mL) and EtOAc (50 mL) were added to precipitate the Bu_3SnI that had formed. The reaction mixture was filtered through Celite and extracted with Et_2O (3 × 30 mL). The organic phase was washed with brine (2 × 15 mL) and dried ($MgSO_4$). Removal of the solvents under reduced pressure yielded **7**, which was further purified by column chromatography (silica gel, PE–Et_2O, 95:5).

(2*E*,4*E*)-Tributylstannyl-5-tributylstannylpenta-2,4-dienoate (7a)
Yield: 64%; yellow oil.

IR (neat): 2957, 2923, 2852, 1631, 1571, 1532, 1387 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.95 (t, *J* = 7.1 Hz, 18 H), 1.32–1.66 (m, 36 H), 5.88 (d, *J* = 15.2 Hz, 1 H), 6.63 (d, *J* = 18.6 Hz, 1 H), 6.77 (dd, *J* = 18.6, 9 Hz, J_{Sn-H} = 74 Hz, 1 H), 7.16 (dd, *J* = 15.2, 9 Hz, J_{Sn-H} = 55 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.5 (J_{Sn-C} = 332–349 Hz, 3 C), 13.5 (6 C), 16.3 (J_{Sn-C} = 343–360 Hz, 3 C), 26.3 (J_{Sn-C} = 54 Hz, 3 C), 26.6 (J_{Sn-C} = 60 Hz, 3 C), 27.7 (J_{Sn-C} = 20.5 Hz, 3 C), 28.9 (J_{Sn-C} = 19 Hz, 3 C), 121.6, 144.6, 145, 145.6, 172.5.

MS (EI, 70 eV): *m*/*z* (%) = 621 (26) [M$^+$ – 57], 291 (47), 235 (52), 177 (81), 121 (25) [organotin fragments], 57 (21), 56 (17), 43 (15), 41 (100), 39 (39) [organic fragments].

(2*Z*,4*E*)-Tributylstannyl-5-tributylstannylpenta-2,4-dienoate (7b)
Yield: 66%; yellow oil.

IR (neat): 2957, 2924, 2852, 1632, 1619, 1561, 1527, 1262 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.85–1.01 (m, 18 H), 1.25–1.74 (m, 36 H), 5.66 (d, *J* = 11.3 Hz, 1 H), 6.24 (dd, *J* = 11.3, 10.5 Hz, 1 H), 6.67 (d, *J* = 18.7 Hz, J_{Sn-H} = 38 Hz, 1 H), 7.80 (dd, *J* = 18.7, 10.5 Hz, J_{Sn-H} = 83–64 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.5 (J_{Sn-C} = 333–352 Hz, 3 C), 13.5 (6 C), 16.4 (J_{Sn-C} = 322–337 Hz, 3 C), 26.9 (J_{Sn-C} = 64 Hz, 3 C), 27.1 (J_{Sn-C} = 54 Hz, 3 C), 27.7 (J_{Sn-C} = 19 Hz, 3 C), 28.9 (J_{Sn-C} = 20 Hz, 3 C), 118.5, 143.0 (J_{Sn-C} = 13 Hz), 144.3 (J_{Sn-C} = 75 Hz), 144.7 (J_{Sn-C} = 346–361 Hz), 171.8.

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –48.8, 103.2.

MS (EI, 70 eV): *m*/*z* (%) = 621 (54) [M$^+$ – 57], 331 (24), 291 (41), 253 (24), 235 (64), 225 (24), 177 (100), 121 (35) [organotin fragments], 57 (37), 55 (20) [organic fragments].

(2*E*,4*E*)-Tributylstannyl-5-tributylstannyl-3-methylpenta-2,4-dienoate (7c)
Yield: 70%; yellow oil.

IR (neat): 2957, 2924, 2874, 2853, 1613, 1566, 1523, 1375, 1075 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.92 (t, *J* = 7 Hz, 9 H), 0.95 (t, *J* = 7 Hz, 9 H), 1.29–1.67 (m, 36 H), 2.25 (d, *J* = 1 Hz, 3 H), 5.86 (s, 1 H), 6.61 (d, *J* = 19.3 Hz, J_{Sn-H} = 60–62 Hz, 1 H), 6.74 (d, *J* = 19.3 Hz, J_{Sn-H} = 62–65 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.4 (J_{Sn-C} = 333–347 Hz, 3 C), 12.9, 13.5 (6 C), 16.3 (J_{Sn-C} = 342–360 Hz, 3 C), 27 (J_{Sn-C} = 63–66 Hz, 3 C), 27.1 (J_{Sn-C} = 53–56 Hz, 3 C), 27.7 (J_{Sn-C} = 20 Hz, 3 C), 28.9 (J_{Sn-C} = 21 Hz, 3 C), 121.4, 135.5 (J_{Sn-C} = 347–363 Hz), 149.6 (J_{Sn-C} = 11 Hz), 150, 173.

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –45.0, 100.6.

MS (EI, 70 eV): *m*/*z* (%) = 633 (11) [M$^+$ – 57], 345 (16), 291 (15), 233 (38), 177 (48), 121 (15) [organotin fragments], 57 (62), 56 (17), 55 (16), 44 (14), 43 (17), 41 (100), 39 (47) [organic fragments].

(2*Z*,4*E*)-Tributylstannyl-5-tributylstannyl-3-methylpenta-2,4-dienoate (7d)
Yield: 69%; yellow oil.

IR (neat): 2957, 2923, 2854, 2871, 1644, 1561, 1516 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.92 (t, *J* = 7 Hz, 9 H), 0.94 (t, *J* = 7 Hz, 9 H), 1.26–1.66 (m, 36 H), 2.00 (s, 3 H), 5.81 (s, 1 H), 6.70 (d, *J* = 19.5 Hz, J_{Sn-H} = 64 Hz, 1 H), 7.97 (d, *J* = 19.5 Hz, J_{Sn-H} = 65 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.4 (J_{Sn-C} = 331–349 Hz, 3 C), 13.5 (6 C), 16.4 (J_{Sn-C} = 342.4–359 Hz, 3 C), 20.1, 26.9 (J_{Sn-C} = 63–66 Hz, 3 C), 27.2 (J_{Sn-C} = 53–56 Hz, 3 C), 27.8 (J_{Sn-C} = 20 Hz, 3 C), 29 (J_{Sn-C} = 21 Hz, 3 C), 119, 137 (J_{Sn-C} = 348–364 Hz), 143.6 (J_{Sn-C} = 12 Hz), 148, 172.

MS (EI, 70 eV): *m*/*z* (%) = 633 (21) [M$^+$ – 57], 401 (6), 235 (25), 233 (36), 177 (54) [organotin fragments], 57 (90), 41 (100), 39 (21) [organic fragments].

^{119}Sn NMR (149 MHz, $CDCl_3$): δ = –43.6, 98.8.

5-Iodopenta-2,4-dienoic Acids 8 by Iododestannylation of Dienoates 7; General Procedure
Acids **8** were prepared from dienoates **7** by the general procedure described above for the synthesis of acids **3**.

(2*E*,4*E*)-5-Iodopenta-2,4-dienoic Acid (8a)
Yield: 64%; colorless oil.

IR (neat): 3058, 1673, 1623, 1231 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.05 (d, *J* = 15.2 Hz, 1 H), 7.17–7.47 (m, 3 H), 8.35 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 90.6, 122.4, 143, 143.3, 167.8.

MS (EI, 70 eV): *m*/*z* (%) = 224 (44) [M$^+$], 127 (10), 97 (67), 69 (29), 51 (81), 45 (26), 41 (100), 39 (38).

Anal. Calcd for $C_5H_5O_2I$: C, 26.81; H, 2.25. Found: C, 26.67; H, 2.22.

(2*Z*,4*E*)-5-Iodopenta-2,4-dienoic Acid (8b)
Yield: 66%; colorless oil.

IR (neat): 3074, 3036, 2754, 2587, 1678, 1609, 1556, 1233 cm^{-1}.

^{1}H NMR (200 MHz, acetone-d_6): δ = 5.73 (d, *J* = 11.3 Hz, 1 H), 6.60 (dd, *J* = 12, 11.3 Hz, 1 H), 7.06 (d, *J* = 14.6 Hz, 1 H), 8.41 (dd, *J* = 14.6, 12 Hz, 1 H), 10.20 (br s, 1 H).

^{13}C NMR (50 MHz, acetone-d_6): δ = 92.8, 116.5, 141.2, 144.9, 170.9.

MS (EI, 70 eV): *m*/*z* (%) = 224 (49) [M$^+$], 127 (10), 97 (68), 52 (65), 51 (82), 45 (25), 41 (100), 39 (38).

Anal. Calcd for $C_5H_5O_2I$: C, 26.81; H, 2.25. Found: C, 26.52; H, 2.38.

(2*E*,4*E*)-5-Iodo-3-methylpenta-2,4-dienoic Acid (8c)
Yield: 64%; yellow crystals; mp 125–127 °C.

IR (KBr): 3065, 2955, 2924, 1678, 1614, 1190, 1269, 1190 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.29 (d, *J* = 0.5 Hz, 3 H), 5.92 (q, *J* = 0.5 Hz, 1 H), 7.19 (d, *J* = 14.8 Hz, 1 H), 7.3 (d, *J* = 14.8 Hz, 1 H), 10.40 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 12.9, 85.2, 120.8, 148.8, 151.7, 167.3.

MS (EI, 70 eV): *m*/*z* (%) = 238 (11) [M$^+$], 127 (10), 111 (100), 66 (17), 65 (25), 55 (59), 45 (12), 43 (20), 41 (17), 39 (77).

Anal. Calcd for $C_6H_7O_2I$: C, 30.27; H, 2.96. Found: C, 30.07; H, 3.04.

(2*Z*,4*E*)-5-Iodo-3-methylpenta-2,4-dienoic Acid (8d)
Yield: 69%; yellow crystals; mp 133–135 °C.

IR (KBr): 3475–2771, 1675, 1619, 1556, 1292, 1211 cm^{-1}.

^1H NMR (50 MHz, acetone-d_6): δ = 2.06 (s, 3 H), 5.72 (s, 1 H), 7.23 (d, *J* = 15.0 Hz, 1 H), 8.71 (d, *J* = 15.0 Hz, 1 H), 10.3 (br s, 1 H).

^{13}C NMR (50 MHz, acetone-d_6): δ = 19.1, 87.2, 117.4, 142.3, 149.6, 166.

MS (EI, 70 eV): *m*/*z* (%) = 127 (8) [M^+ – 111], 111 (100), 83 (13), 55 (45), 43 (19), 41 (13), 39 (59).

Anal. Calcd for $C_6H_7O_2I$: C, 30.27; H, 2.96. Found: C, 29.84; H, 3.19.

(2*Z*,4*E*)-5-Iodo-3-methyl[2-^{2}H]penta-2,4-dienoic Acid (8e)
Yield: 74%; yellow crystals; mp 189–191 °C.

IR (KBr): 3475–2771, 1676, 1619, 1556, 1292 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 2.0 (s, 3 H), 7.06 (d, *J* = 15 Hz, 1 H), 8.62 (d, *J* = 15.0 Hz, 1 H), 9.8 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 21, 88.6, 117, 142.8, 152, 171.

MS (EI, 70 eV): *m*/*z* (%) = 239 (1) [M^+], 127 (10), 112 (100), 111 (11), 84 (15), 67 (18), 66 (25), 56 (55), 43 (30), 40 (52), 39 (44).

(2*Z*,4*E*)-5-Iodo-3-ethylpenta-2,4-dienoic Acid (8f)
Yield: 70%; colorless oil.

IR (neat): 3432, 3074, 1685, 1616, 1556, 1264, 1264 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 1.15 (t, *J* = 7.4 Hz, 3 H), 2.38 (q, *J* = 7.4 Hz, 2 H), 5.67 (s, 1 H), 7.0 (d, *J* = 15.0 Hz, 1 H), 8.51 (d, *J* = 15.0 Hz, 1 H), 11.3 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 13.5, 26.9, 87.6, 115.6, 141.9, 157.5, 171.3.

MS (EI, 70 eV): *m*/*z* (%) = 252 (2) [M^+], 234 (10), 156 (10), 142 (12), 128 (71), 127 (67), 126 (16), 125 (100), 108 (15), 107 (19), 81 (11), 79 (32), 77 (20), 67 (11), 53 (12), 52 (12), 51 (14), 50 (12).

Anal. Calcd for $C_7H_9O_2I$: C, 33.36; H, 3.60. Found: C, 33.52; H, 3.51.

(2*E*,4*E*)-5-Iodo-3-propylpenta-2,4-dienoic Acid (8g)
Yield: 67%; colorless oil.

IR (neat): 3429, 3073, 2958, 2871, 1693, 1607, 1416, 1265, 1183, 948 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.98 (t, *J* = 7.4 Hz, 3 H), 1.52 (sext, *J* = 7.4 Hz, 2 H), 2.73 (t, *J* = 7.4 Hz, 2 H), 5.76 (s, 1 H), 6.99 (d, *J* = 15.0 Hz, 1 H), 7.51 (d, *J* = 15.0 Hz, 1 H), 11.3 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 14.6, 23.2, 29.7, 85.7, 119.2, 147.5, 158.7, 172.

MS (EI, 70 eV): *m*/*z* (%) = 266 (3) [M^+], 237 (15), 221 (25), 139 (100), 128 (67), 127 61), 43 (48).

Anal. Calcd for $C_8H_{11}O_2I$: C, 36.11; H, 4.17. Found: C, 35.93; H, 4.23.

(2*Z*,4*E*)-5-Iodo-3-propylpenta-2,4-dienoic Acid (8h)
Yield: 73%; colorless oil.

IR (neat): 3432, 3071, 1691, 1613, 1556, 1257, 957 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.97 (t, *J* = 7.5 Hz, 3 H), 1.57 (sext, *J* = 7.5 Hz, 2 H), 2.33 (td, *J* = 7.5, 1.0 Hz, 2 H), 5.68 (t, *J* = 1.0 Hz, 1 H), 7.05 (d, *J* = 15.0 Hz, 1 H), 8.52 (dd, *J* = 15.0, 1.0 Hz, 1 H), 11.3 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 8.4, 14.3, 36.2, 87.9, 116.5, 141.9, 156.1, 171.6.

MS (EI, 70 eV): *m*/*z* (%) = 266 (8) [M^+], 139 (100), 128 (18), 127 (10), 110 (15), 79 (12), 77 (14), 55 (11), 53 (10), 51 (14).

Anal. Calcd for $C_8H_{11}O_2I$: C, 36.11; H, 4.17. Found: C, 35.93; H, 4.23.

(2*Z*,4*E*,6*Z*)-3,6-Dimethylocta-2,4,6-trienedioic Acid (8i)
Yield: 71%; colorless oil.

IR (neat): 3068–2600, 2361, 1675, 1620, 1556, 1284, 1211, 1170 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 2.50 (s, 6 H), 6.01 (s 2 H), 6.78 (s, 2 H), 7.50 (br s, 2 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 21.2, 119.4, 128.1, 150.2, 170.8.

MS (EI, 70 eV): *m*/*z* (%) = 196 (48) [M^+], 153 (19), 152 (100), 107 (73), 67 (32), 45 (66), 44 (28), 41 (55), 39 (71).

Trienoic Acids 9 by Cross-Coupling of Acids 8 with Vinylstannanes; General Procedure
Acids **9** were prepared from acids **8** and vinylstannanes by the general procedure described above for the synthesis of dienoic acids **4**.

(2*E*,4*E*)-Hepta-2,4,6-trienoic Acid (9a)
Yield: 88%; colorless oil.

IR (neat): 3400–2500, 1695, 1641, 1620, 1256 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 5.43 (d, *J* = 9.5 Hz, 1 H), 5.50 (d, *J* = 16.5 Hz, 1 H), 5.95 (d, *J* = 15.3 Hz, 1 H), 6.32–6.72 (m, 3 H), 7.44 (dd, *J* = 15.3, 11.1 Hz, 1 H), 8.50 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 121.1 (2 C), 123.1, 130.7, 142.7, 147.2, 173.1.

MS (EI, 70 eV): *m*/*z* (%) = 124 (28) [M^+], 79 (100), 53 (15), 52 (15), 45 (10), 39 (29).

(2*Z*,4*E*)-Hepta-2,4,6-trienoic Acid (9b)
Yield: 84%; colorless oil.

IR (neat): 3300–2500, 1695, 1618, 1610, 1572, 1259 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 5.40 (d, *J* = 9.1 Hz, 1 H), 5.49 (d, *J* = 14.8 Hz, 1 H), 5.74 (d, *J* = 11.3 Hz, 1 H), 6.44–6.64 (m, 2 H), 6.76 (dd, *J* = 11.5, 11.3 Hz, 1 H), 7.55 (dd, *J* = 12.7, 11.5 Hz, 1 H), 10.40 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 117.5, 122.9, 129.5, 137.1, 143.5, 147.3, 172.9.

MS (EI, 70 eV): *m*/*z* (%) = 124 (20) [M^+], 79 (100), 78 (19), 51 (23), 39 (25).

(2*Z*,4*E*)-3-Methylhepta-2,4,6-trienoic Acid (9c)
Yield: 96%; yellow oil.

IR (neat): 3483, 3059, 3024, 2577, 1700, 1609, 1556, 1178 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 2.11 (d, *J* = 1.1 Hz, 3 H), 5.37 (dd, *J* = 8.7, 2 Hz, 1 H), 5.48 (dd, *J* = 16.1, 2 Hz, 1 H), 5.77 (q, *J* = 1.1 Hz, 1 H), 6.56–6.69 (m, 2 H), 7.76 (d, *J* = 14.4 Hz, 1 H), 10.38 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 21.0, 116.9, 121.3, 129.8, 137, 137.1, 153, 171.8.

MS (EI, 70 eV): *m*/*z* (%) = 138 (22) [M^+], 93 (100), 53 (14), 51 (18), 41 (20), 39 (41).

(2*Z*,4*E*)-3,7-Dimethylocta-2,4,6-trienoic Acid (9d)
Yield: 74%; yellow oil.

IR (neat): 3483, 3064, 3030, 1638, 1617, 1568 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.9 (s, 6 H), 2.12 (s, 3 H), 5.68 (s, 1 H), 6.11 (d, *J* = 10.7 Hz, 1 H), 6.9 (dd, *J* = 15.2, 10.7 Hz, 1 H), 7.65 (d, *J* = 15.2 Hz, 1 H), 10.8 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 18.6, 21.1, 26.4, 115.2, 125.9, 126.9, 133.1, 141.3, 154, 172.

MS (EI, 70 eV): *m*/*z* (%) = 166 (37) [M$^+$], 121 (100), 107 (95), 105 (66), 93 (19), 43 (64), 41 (92), 40 (24), 39 (87).

(2*Z*,4*E*,6*E*)-9,9-Diethoxy-3-methylnona-2,4,6-trienoic Acid (9e)
Yield: 72%; yellow oil.

IR (neat): 3450, 3063, 3028, 1671, 1662, 1640, 1607, 1247 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7.0 Hz, 6 H), 2.07 (s, 3 H), 2.52 (t, *J* = 6.2 Hz, 2 H), 3.47–3.77 (m, 4 H), 4.57 (t, *J* = 6.2 Hz, 1 H), 5.7 (s, 1 H), 5.93 (dt, *J* = 15.1, 6.2 Hz, 1 H), 6.35 (dd, *J* = 15.2, 10.5 Hz, 1 H), 6.65 (dd, *J* = 15, 10.5 Hz, 1 H), 7.67 (d, *J* = 15.2 Hz, 1 H), 9.68 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 15.1 (2 C), 20.7, 37.4, 61.1 (2 C), 102, 116.2, 128.4, 132.8, 133.3, 135.6, 153, 171.3.

MS (EI, 70 eV): *m*/*z* (%) = 163 (4) [M$^+$], 111 (95), 103 (92), 101 (26), 91 (11), 75 (64), 73 (43), 69 (28), 68 (14), 55 (18), 47 (94), 46 (17), 45 (95), 41 (58), 39 (60), 31 (100).

(2*Z*,4*E*,6*E*)-3-Methyl-7-(trimethylsilyl)hepta-2,4,6-trienoic Acid (9f)
Yield: 86%; yellow oil.

IR (neat): 3159, 2959, 2929, 2680, 1680, 1657, 1605, 1261 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.15 (s, 9 H), 2.10 (s, 3 H), 5.76 (s, 1 H), 6.19 (d, *J* = 17.2 Hz, 1 H), 6.64 (dd, *J* = 14.6, 10.2 Hz, 1 H), 6.79 (dd, *J* = 17.2, 10.2 Hz, 1 H), 7.75 (d, *J* = 14.6 Hz, 1 H), 11.66 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –1.5, 21, 117.5, 129.6, 138.8, 140, 143.9, 153.3, 171.4.

MS (EI, 70 eV): *m*/*z* (%) = 210 (2) [M$^+$], 91 (10), 75 (100), 73 (41), 45 (19), 43 (16).

(2*Z*,4*E*)-3-Methylhepta-2,4-dien-6-ynoic Acid (9g)
Yield: 79%; colorless oil.

IR (neat): 3472, 3262, 2957, 2925, 1677, 1638, 1619, 1579, 1266 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.07 (s, 3 H), 3.27 (s, 1 H), 5.81 (s, 1 H), 6.04 (d, *J* = 16.3 Hz, 1 H), 8.16 (d, *J* = 16.3 Hz, 1 H), 10.6 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 20.3, 82.9, 92.2, 114.7, 118.5, 139.4, 150.9, 170.

MS (EI, 70 eV): *m*/*z* (%) = 136 (39) [M$^+$], 119 (10), 91 (82), 90 (20), 89 (17), 65 (78), 51 (45), 50 (43), 45 (26), 43 (14), 39 (100), 38 (24), 32 (29).

Hepta-2,4-dien-6-ynoic Acids 10 by Cross-Coupling of Acids 8 with Alkynes; General Procedure
These reactions were performed according to a previously reported method.[38]

(2*Z*,4*E*)-7-Phenylhepta-2,4-dien-6-ynoic Acid (10a)
Yield: 75%; colorless oil.

IR (neat): 3098, 2186, 1687, 1610, 1596, 1168 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.82 (d, *J* = 11.3 Hz, 1 H), 6.24 (d, *J* = 15.6 Hz, 1 H), 6.78 (t, *J* = 11.4 Hz, 1 H), 7.39–7.59 (m, 5 H), 8.0 (dd, *J* = 15.6, 11.4 Hz, 1 H), 11.1 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 89.0, 97.5, 118.7, 123.2, 128.9 (2 C), 129.7, 132.3, 133 (2 C), 137.3, 145.9, 172.2.

(2*Z*,4*E*)-3-Methyl-7-phenylhepta-2,4-dien-6-ynoic Acid (10b)
Yield: 75%; yellow crystals; mp 169–171 °C.

IR (KBr): 3070, 2980, 2870, 2185, 1685, 1610, 1595, 1170 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.12 (s, 3 H), 5.76 (s, 1 H), 6.25 (d, *J* = 16 Hz, 1 H,), 7.31–7.3 (m, 3 H, Ar), 7.48–7.46 (m, 2 H, Ar), 8.1 (d, *J* = 16 Hz, 1 H), 9.6 (br s, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 20.7, 89, 96, 116, 118, 123, 128.5, 128.8, 132, 137.7, 151.8, 171.4.

MS (EI, 70 eV): *m*/*z* (%) = 212 (33) [M$^+$], 197 (61), 165 (67), 115 (35), 105 (100), 83 (20), 77 (32), 39 (24).

(2*Z*,4*E*)-3-Methyl-7-(trimethylsilyl)hepta-2,4-dien-6-ynoic Acid (10c)
Yield: 77%; yellow crystals; mp 111–113 °C.

IR (KBr): 3100, 2985, 2875, 2200, 1690, 1615, 1170 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.25 (s, 9 H), 2.05 (d, *J* = 1 Hz, 3 H), 5.78 (q, *J* = 1 Hz, 1 H), 6.08 (d, *J* = 16 Hz, 1 H), 8.09 (d, *J* = 16 Hz, 1 H), 11.8 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 0.2 ($J_{Si–C}$ = 56 Hz, 3 C), 21, 102, 104, 116, 118, 119, 139, 152, 172.

MS (EI, 70 eV): *m*/*z* (%) = 208 (13) [M$^+$], 193 (54), 149 (27), 75 (100), 73 (19), 45 (44), 43 (37).

(2*E*,4*E*)-3-Methyl-7-(tributylgermyl)hepta-2,4-dien-6-ynoic Acid (10f)
Yield: 72%; colorless oil.

IR (neat): 3100, 2980, 2875, 2200, 1690, 1615, 1170 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7 Hz, 9 H), 1.5–1.34 (m, 18 H), 2.3 (s, 3 H), 5.86 (s, 1 H), 6.11 (d, *J* = 16 Hz, 1 H), 6.68 (d, *J* = 16 Hz, 1 H), 9.4 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 13.7, 14.2 (3 C), 14.5 (3 C), 26.5 (3 C), 27.8 (3 C), 101.5, 104.7, 116, 120, 144.3, 154, 172.

MS (EI, 70 eV): *m*/*z* (%) = 323 (22) [M$^+$ – 56], 267 (20), 91 (44), 57 (23), 43 (11), 41 (100).

6-[(*E*)-But-1-en-3-ynyl]-1,5,5-trimethylcyclohexene (12b)
Compound **12b** was prepared by a method described by Negishi.[40]

Yield: 86%; yellow oil.

IR (neat): 3300, 3200, 2100, 1633, 1608, 956 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.84 (s, 3 H), 0.89 (s, 3 H), 1.15–1.44 (m, 2 H), 1.57 (m, 3 H), 1.98 (m, 2 H), 2.15 (d, *J* = 9.6 Hz, 1 H), 2.78 (dd, *J* = 2.2, 0.6 Hz, 1 H), 5.42 (m, 1 H), 5.43 (ddd, *J* = 15.8, 2.2, 0.6 Hz, 1 H), 6.07 (ddd, *J* = 15.8, 9.6, 0.6 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 23.2, 23.4, 27.2, 28.0, 31.7, 32.7, 55.1, 76.6, 82.8, 110.3, 122.2, 133.0, 141.2.

MS (EI, 70 eV): *m*/*z* (%) = 174 (8) [M$^+$], 159 (16), 118 (63), 117 (100), 115 (14), 103 (22), 91 (15).

1-[(*E*)-But-1-en-3-ynyl]-2,6,6-trimethylcyclohexa-1,3-diene (12c)
A two-necked, 250-mL flask equipped with an argon bubbler, a magnetic stirring bar, and a rubber septum was charged with triphenyl[3-(trimethylsilyl)prop-2-ynyl]phosphonium bromide (21.5 g, 47 mmol) and dry THF (70 mL), and the flask was cooled with an ice–water bath. Then, 1 M LDA in THF (50 mL, 50 mmol) was added dropwise to this soln. The mixture was stirred for 1 h, and safranal (4.05 g, 26.7 mmol) in dry THF (30 mL) was added at –5 °C, after which stirring was continued for 15 h at 0 °C. The resulting dark soln was quenched with sat. aq NH_4Cl (50 mL) at 0 °C and extracted with Et_2O (3 × 50 mL). The combined organic layers were washed with brine (2 × 20 mL), dried ($MgSO_4$), and concentrated in

vacuo. The crude product was diluted with an Et_2O–PE mixture (20:80; 100 mL), the insoluble material (Ph_3PO) was removed by filtration, and the solvent was evaporated. The residue was purified by column chromatography (PE–Et_2O, 90:10); this gave 1-[(*E*)-4-(trimethylsilyl)but-1-en-3-ynyl]-2,6,6-trimethylcyclohexa-1,3-diene.

1-[(*E*)-4-(Trimethylsilyl)but-1-en-3-ynyl]-2,6,6-trimethylcyclohexa-1,3-diene
Yield: 5.1 g (78%); yellow oil.

IR (neat): 3050, 2970, 2150, 1260, 850 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.17 (s, 9 H), 0.98 (s, 6 H), 1.83 (s, 3 H), 2.03 (d, *J* = 3.9 Hz, 2 H), 5.57 (d, *J* = 16.5 Hz, 1 H), 5.69 (dt, *J* = 9.5, 3.9 Hz, 1 H), 5.80 (d, *J* = 9.5 Hz, 1 H), 6.60 (d, *J* = 16.5 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = –0.1 ($J_{Si–C}$ = 46 Hz, 3 C), 20.1, 26.5 (2 C), 33.6, 39.7, 95.1, 104.9, 111.1, 126.1, 128.8, 129.5, 137.0, 140.5.

MS (EI, 70 eV): *m*/*z* (%) = 244 (18) [M^+], 73 (100), 59 (15).

A 1 M soln of TBAF in THF (8.3 mL, 8.2 mmol) was added to a soln of 1-[(*E*)-4-(trimethylsilyl)but-1-en-3-ynyl]-2,6,6-trimethylcyclohexa-1,3-diene (1 g, 4.1 mmol) in dry THF (20 mL) at –5 °C, and the mixture was stirred at r.t. for 2 h. The resulting dark soln was quenched with sat. aq NH_4Cl (10 mL) at 0 °C and extracted with Et_2O (3 × 20 mL). The combined organic layers were washed with brine (2 × 15 mL), dried ($MgSO_4$), and concentrated in vacuo. Purification of the residue by column chromatography (PE–Et_2O, 95:5) gave **12c**.

1-[(*E*)-But-1-en-3-ynyl]-2,6,6-trimethylcyclohexa-1,3-diene (12c)
Yield: 0.58 g (82%); yellow oil.

IR (neat): 3320, 3055, 2980, 2120, 965 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.99 (s, 6 H), 1.83 (s, 3 H), 2.04 (d, *J* = 3.4 Hz, 2 H), 2.98 (d, *J* = 2.3 Hz, 1 H), 5.52 (dd, *J* = 16.5, 2.3 Hz, 1 H), 5.73 (dt, *J* = 9.8, 3.4 Hz, 1 H), 5.81 (d, *J* = 9.8 Hz, 1 H), 6.65 (d, *J* = 16.5 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 20.7, 27.2 (2 C), 34.3, 40.3, 78.6, 84.1, 110.8, 126.9, 129.5, 130.1, 137.5, 142.0.

MS (EI, 70 eV): *m*/*z* (%) = 172 (33) [M^+], 157 (49), 143 (13), 142 (100), 141 (49), 129 (17), 128 (16), 115 (30), 91 (13), 77 (16), 65 (11), 63 (12), 51 (17), 41 (13), 39 (25).

Stannanes 13a and 13b; General Procedure
A soln of 1.6 M BuLi in hexane (24.3 mL, 39 mmol) was added dropwise to a heterogeneous soln of CuCN (1.75 g, 19.5 mmol) in THF (80 mL), at –78 °C, in a 100-mL four-necked flask flushed with argon. After 10 min, Bu_3SnH (10.5 mL, 39 mmol) was added; the mixture became yellow and H_2 evolved. The temperature of the soln of was reduced to –90 °C, MeOH (100 equiv) and alkyne **12a** or **12b** (2.61 g, 15 mmol) in THF (20 mL) were successively added dropwise. After 2 h at –78 °C, the mixture was hydrolyzed with a sat. NH_4Cl soln and filtered through Celite. The aqueous phase was extracted with Et_2O (3 × 50 mL). The organic phases were combined, washed with brine (2 × 20 mL), and dried ($MgSO_4$), and the solvents were evaporated to give vinylstannane **13**.

Tributyl[(1*E*,3*E*)-4-(2,6,6-trimethylcyclohex-1-enyl)buta-1,3-dienyl]stannane (13a)
Yield: 85%; yellow oil.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.93 (t, *J* = 7.2 Hz, 9 H), 0.97 (m, 6 H), 1.07 (s, 6 H), 1.25–1.66 (m, 16 H), 1.75 (s, 3 H), 2.05 (t, *J* = 6.1 Hz, 2 H), 6.13 (m, 2 H), 6.18 (d, *J* = 18.9 Hz, $J_{Sn–H}$ = 72 Hz, 1 H), 6.55 (ddd, *J* = 18.9, 7.1, 1.5 Hz, $J_{Sn–H}$ = 61 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.8 ($J_{Sn–C}$ = 328–343 Hz, 3 C), 13.5 (3 C), 19.2, 21.5, 27.3 ($J_{Sn–C}$ = 50–64 Hz, 3 C), 28.8 (2 C), 29.1 ($J_{Sn–C}$ = 20.0 Hz, 3 C), 33, 34.1, 39.7, 130.1, 129.4, 130.9 ($J_{Sn–C}$ = 393–376 Hz, 1 C), 136.5 ($J_{Sn–C}$ = 74 Hz, 1 C), 137.2, 147.7 ($J_{Sn–C}$ = 9.3 Hz, 1 C).

Stannanes 14a and 14b
After the stannylcuprate prepared from the corresponding alkyne **12** [as described above for the synthesis of compounds **13**] had stirred for 2 h at –90 °C, MeI (12.1 mL, 195 mmol) was added. The soln was allowed to warm to 25 °C, and the mixture was stirred for 12 h. The mixture was hydrolyzed with a sat. soln of NH_4Cl and extracted with Et_2O (3 × 20 mL). The organic phases were washed with brine and dried ($MgSO_4$), and the solvents were removed under reduced pressure. Compounds **14** were obtained contaminated with the corresponding internal isomers **15b** (<10%), but were used without purification.

Tributyl[(1*E*,3*E*)-2-methyl-4-(2,6,6-trimethylcyclohex-1-enyl)buta-1,3-dienyl]stannane (14a)
Yield: 78%; yellow oil.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7.2 Hz, 9 H), 0.98 (m, 6 H), 1.07 (s, 6 H), 1.25–1.66 (m, 16 H), 1.75 (s, 3 H), 1.96 (s, 3 H), 2.05 (t, *J* = 6.0 Hz, 2 H), 5.88 (s, $J_{Sn–H}$ = 68 Hz, 1 H), 6.06 (d, *J* = 16.2 Hz, 1 H), 6.18 (d, *J* = 16.2 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 10.1 ($J_{Sn–C}$ = 326–341 Hz, 3 C), 13.6 (3 C), 19.2, 20.5, 21.5, 27.3 ($J_{Sn–C}$ = 50–63.7 Hz, 3 C), 28.8 (2 C), 29.1 ($J_{Sn–C}$ = 20 Hz, 3 C), 32.9, 34.1, 39.5, 125.4, 128.6, 130.9 ($J_{Sn–C}$ = 391–407 Hz, 1 C), 137.5, 138.7 ($J_{Sn–C}$ = 71 Hz, 1 C), 150.8 ($J_{Sn–C}$ = 29 Hz, 1 C).

MS (EI, 70 eV): *m*/*z* (%) = 423 (100) [M^+ – 57], 311 (4), 309 (15), 235 (23), 209 (14), 207 (30), 193 (15), 179 (44), 177 (41), 123 (11), 121 (30) [organotin fragments], 189 (17), 181 (12), 133 (44), 131 (34), 107 (13), 105 (44), 93 (16), 91 (21), 81 (12), 79 (16), 77 (12), 69 (41), 62 (16), 55 (22), 48 (17), 43 (12), 41 (56), 40 (21), 39 (14), 31 (14) [organic fragments].

Tributyl[(1*E*,3*E*)-2-methyl-4-(2,6,6-trimethylcyclohex-2-enyl)buta-1,3-dienyl]stannane (14b)
Yield: 83%; yellow oil.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 7.1 Hz, 9 H), 1.28–1.58 (m, 29 H), 1.87 (s, 3 H), 2.00 (m, 2 H), 2.12 (d, *J* = 9.1 Hz, 1 H), 5.37 (dd, *J* = 15.6, 9.1 Hz, 1 H), 5.40 (m, 1 H), 5.80 (s, $J_{Sn–H}$ = 68 Hz, 1 H), 6.12 (d, *J* = 15.8 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 9.1 ($J_{Sn–C}$ = 299–311 Hz, 3 C), 14.1 (3 C), 19.2, 23.4, 23.6, 27.7, 28.9 ($J_{Sn–C}$ = 53 Hz, 3 C), 29.6 ($J_{Sn–C}$ = 25 Hz, 3 C), 29.8, 32.2, 32.7, 55.0, 121.1, 130.1, 130.6, 137.5, 151.1.

(2*Z*,4*E*,6*E*,8*E*)-3,7-Dimethyl-9-(2,6,6-trimethylcyclohex-1-enyl)nona-2,4,6,8-tetraenoic Acid (13-*cis*-Retinoic Acid) (16b); Typical Procedure
$[PdCl_2(NCMe)_2]$ (3%, 16 mg, 0.063 mmol) was added to a DMF soln (15 mL) of **14a** (1.20 g, 2.52 mmol) and **8d** (0.5 g, 2.1 mmol) in a 50-mL flask. The mixture was stirred for 3 h at 25 °C before being washed with a sat. soln of NH_4Cl (2 × 15 mL) and extracted with Et_2O (3 × 30 mL). After the usual workup, the crude **16b** was purified by column chromatography (silica gel, PE–Et_2O, 95:5, then 70:30) and crystallization (Et_2O).

Yield: 70%; orange crystals; mp 161 °C (Lit. = 162–164 °C).

IR (KBr): 3264, 3062, 2956, 2921, 2851, 2581, 1682, 1605, 1562, 1276, 1225, 994 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.01 (s, 6 H), 1.43–1.47 (m, 2 H), 1.58–1.61 (m, 2 H), 1.70 (s, 3 H), 1.98 (s, 3 H), 2.01 (t, *J* = 5.7 Hz, 2 H), 2.08 (s, 3 H), 5.64 (s, 1 H), 6.15 (d, *J* = 16 Hz, 1 H), 6.25 (d, *J* = 11 Hz, 1 H), 6.27 (d, *J* = 16 Hz, 1 H), 7.01 (dd, *J* = 15.2 Hz, *J* = 11 Hz, 1 H), 7.73 (d, *J* = 15.2 Hz, 1 H), 10.7 (br s, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 12.8, 19.1, 21.1, 21.6, 28.8 (2 C), 33.0, 34.1, 39.5, 115.7, 128.7, 129.1, 130.0, 130.1, 132.9, 137.2, 137.5, 140.3, 153.5, 172.

MS (EI, 70 eV): *m*/*z* (%) = 300 (41) [M$^+$], 285 (95), 239 (66), 197 (16), 185 (11), 143 (11), 133 (13), 129 (24), 99 (11), 89 (54), 88 (70), 87 (35), 85 (16), 73 (46), 72 (15), 71 (13), 61 (12), 60 (28), 59 (13), 58 (63), 57 (39), 45 (100), 44 (43).

(2*E*,4*E*,6*E*,8*E*)-7-Methyl-9-(2,6,6-trimethylcyclohex-1-enyl)nona-2,4,6,8-tetraenoic Acid (All-*trans*-9-*nor*-retinoic Acid) (16a)

Yield: 55%; colorless oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.06 (s, 6 H), 1.45–1.49 (m, 2 H), 1.60–1.63 (m, 2 H), 1.75 (s, 3 H), 2.02 (s, 3 H), 2.07 (t, *J* = 5.7 Hz, 2 H), 5.90 (d, *J* = 15 Hz, 1 H), 6.17 (d, *J* = 15.9 Hz, 1 H), 6.20–6.30 (m, 2 H), 6.35 (d, *J* = 15.9 Hz, 1 H), 6.99 (dd, *J* = 15, 11.6 Hz, 1 H), 7.44 (dd, *J* = 14.9, 11.6 Hz, 1 H), 10.7 (br s, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 12.8, 19.1, 21.7, 28.8 (2 C), 33.0, 34.1, 39.4, 114.8, 127.4, 130.4, 131.7, 132.8, 134.9, 137.5, 138.6, 143.1, 147, 172.

(2*Z*,4*E*,6*E*,8*E*)-7-Methyl-9-(2,6,6-trimethylcyclohex-1-enyl)nona-2,4,6,8-tetraenoic Acid [(13*Z*)-9-*nor*-Retinoic Acid)] (16d)

Yield: 45%; colorless oil.

IR (neat): 3264, 3062, 2958, 2920, 2851, 1681, 1604, 1560, 1276, 1247 cm^{-1}.

Raman-IR: 1592, 1161 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.07 (s, 6 H), 1.45–1.55 (m, 2 H), 1.60–1.70 (m, 2 H), 1.76 (s, 3 H), 2.04 (s, 3 H), 2.07 (t, *J* = 5.7 Hz, 2 H), 5.67 (d, *J* = 11.2 Hz, 1 H), 6.19 (d, *J* = 16 Hz, 1 H), 6.28 (d, *J* = 11.8 Hz, 1 H), 6.37 (d, *J* = 16 Hz, 1 H), 6.82 (dd, *J* = 11.5, 11.2 Hz, 1 H), 6.96 (dd, *J* = 11.8, 14.6 Hz, 1 H), 7.56 (dd, *J* = 14.6, 11.5 Hz, 1 H), 9.52 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 12.7, 19.1, 21.6, 28.8 (2 C), 33.0, 34.1, 39.5, 114.6, 128.1, 129.4 (2 C), 130.3, 137.0, 139.1, 140.7, 143.1, 147.3, 171.8.

(2*Z*,4*E*,6*E*,8*E*)-3,7-Dimethyl-9-(2,6,6-trimethylcyclohex-2-enyl)nona-2,4,6,8-tetraenoic Acid (16e)

Yield: 55%; yellow crystals; mp 169–171 °C.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.81 (s, 3 H), 0.89 (s, 3 H), 1.17 (dt, *J* = 13.2, 4.7 Hz, 1 H), 1.44 (dt, *J* = 13.2, 8.1 Hz, 1 H), 1.57 (s, 3 H), 1.93 (s, 3 H), 2.01 (m, 2 H), 2.08 (s, 3 H), 2.18 (d, *J* = 9.4 Hz, 1 H), 5.41 (m, 1 H), 5.64 (dd, *J* = 15.3, 9.4 Hz, 1 H), 5.65 (br s, 1 H), 6.13 (d, *J* = 15.3 Hz, 1 H), 6.24 (d, *J* = 11.3 Hz, 1 H), 6.97 (dd, *J* = 15.3, 11.3 Hz, 1 H), 7.73 (d, *J* = 15.3, 1 H), 11.5 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 13.4, 21.3, 23.1, 23.2, 27.1, 27.8, 31.7, 32.6, 54.9, 115.7, 121.2, 129.2, 129.8, 133.1, 133.4, 134.2, 135.9, 140.1, 153.7, 171.5.

MS (EI, 70 eV): *m*/*z* (%) = 256 (22) [M$^+$ – 44], 200 (12), 185 (23), 159 (10), 157 (15), 149 (23), 145 (23), 143 (17), 134 (16), 133 (100), 132 (19), 131 (12), 129 (14), 122 (20), 121 (12), 120 (36), 119 (28), 117 (15), 115 (11), 107 (38), 106 (11), 105 (50), 94 (11), 93 (42), 92 (11), 91 (51), 81 (20), 79 (33), 77 (33), 69 (11), 67 (12), 65 (16), 55 (28), 53 (18), 43 (13), 41 (62), 39 (23).

Didehydro Retinoid Acids 18; General Procedure[38]

A soln of $BuNH_2$ (1 mL, 10 mmol) and alkyne **12** (6.3 mmol) in DMF (20 mL) was stirred under an argon atmosphere for 15 min at r.t. Then acid **17** (217 mg, 4.2 mmol), [$PdCl_2(PPh_3)_2$] (0.31 mmol), and CuI (59 mg, 0.31 mmol) were added. After 4 h at r.t., the mixture was poured into H_2O (20 mL) and extracted with Et_2O (3 × 25 mL); the organic phases were washed with a sat. soln of NH_4Cl (3 × 10 mL) and dried ($MgSO_4$). After the solvents had been evaporated under reduced pressure, the residue was purified by column chromatography (silica gel, hexane–Et_2O, 30:70) or by crystallization (Et_2O).

(2*Z*,4*E*,8*E*)-9-(2,6,6-Trimethylcyclohex-1-enyl)nona-2,4,8-trien-6-ynoic Acid (18a)

Yield: 70%; yellow oil.

IR (neat): 3090, 2990, 2882, 2190, 1685, 1505, 1175 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.06 (s, 6 H), 1.6–1.4 (m, 4 H), 1.73 (s, 3 H), 2.04 (t, *J* = 6 Hz, 2 H), 5.64 (dd, *J* = 16.2, 2.2 Hz, 1 H), 5.7 (d, *J* = 11 Hz, 1 H), 6.12 (d, *J* = 15.5, 1 H), 6.65–6.78 (m, 2 H), 7.85 (dd, *J* = 15.5, 11.7 Hz, 1 H), 10.08 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 19.5, 22, 29.3 (2 C), 33.7, 34.5, 40, 89.6, 98, 112, 118, 122, 133.3, 136.6, 137.5, 143.2, 146, 171.8.

MS (EI, 70 eV): *m*/*z* (%) = 270 (95) [M$^+$], 255 (100), 209 (79), 183 (40), 165 (33), 155 (69), 141 (34), 91 (39), 55 (37), 41 (95).

(2*Z*,4*E*,8*E*)-3-Methyl-9-(2,6,6-trimethylcyclohex-1-enyl)nona-2,4,8-trien-6-ynoic Acid (18b)

Yield: 80%; Yellow crystals; mp 114 °C.

IR (KBr): 3100, 2980, 2875, 2188, 1680, 1605, 1160 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.07 (s, 6 H), 1.67–1.64 (m, 4 H), 1.78 (s, 3 H), 2.00–2.03 (m, 2 H), 2.08 (s, 3 H), 5.68 (dd, *J* = 16, 2.3 Hz, 1 H), 5.76 (s, 1 H), 6.22 (dd, *J* = 16, 2.3 Hz, 1 H), 6.71 (d, *J* = 16 Hz, 1 H), 8.05 (d, *J* = 16 Hz, 1 H), 9.1 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 19.4, 20.9, 22.1, 29.3 (2 C), 33.7, 34.5, 40, 89.3, 96.7, 112.1, 116.9, 118, 133, 137.2, 137.5, 142.7, 152.2, 171.7.

MS (EI, 70 eV): *m*/*z* (%) = 284 (53) [M$^+$], 269 (100), 223 (68), 169 (52), 128 (27), 115 (27), 91 (36), 43 (32), 41 (76), 39 (38).

(2*Z*,4*E*,8*E*)-3-Methyl-9-(2,6,6-trimethylcyclohex-1-enyl)[2-^{2}H]nona-2,4,8-trien-6-ynoic Acid (18c)

Yield: 73%; yellow crystals; mp 135–137 °C.

IR: 3100, 2980, 2877, 2295, 2195,1690, 1605, 1155 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.02 (s, 6 H), 1.61–1.42 (m, 4 H), 1.72 (s, 3 H), 2 (t, *J* = 4 Hz, 2 H), 2.02 (s, 3 H), 5.64 (dd, *J* = 16, 2 Hz, 1 H), 6.18 (dd, *J* = 16, 2 Hz, 1 H), 6.66 (d, *J* = 16 Hz, 1 H), 8.0 (d, *J* = 16 Hz, 1 H), 11 (br s, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19, 20.6, 21.8, 29 (2 C), 33.4, 34.2, 39.7, 89.4, 96.4, 111.8, 116.6, 117.5 (t, J_{C-D} = 27 Hz), 132.6, 137, 137.2, 142.4, 151.8, 170.6.

MS (EI, 70 eV): *m*/*z* (%) = 285 (56) [M$^+$], 270 (100), 224 (65), 170 (41), 129 (22), 91 (30), 55 (30), 45 (24), 43 (34), 41 (89).

(2*Z*,4*E*,8*E*)-3-Ethyl-9-(2,6,6-trimethylcyclohex-1-enyl)nona-2,4,8-trien-6-ynoic Acid (18d)

Yield: 76%; yellow crystals; mp 94–96 °C.

IR (KBr): 3095, 2980, 2878, 2185, 1685,1605, 1165 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.07 (s, 3 H), 1.19 (t, *J* = 7.4 Hz, 3 H), 1.6–1.47 (m, 4 H), 1.78 (s, 3 H), 2.06 (t, *J* = 6 Hz, 2 H), 2.45 (q, *J* = 7.4 Hz, 2 H), 5.7 (dd, *J* = 16, 2 Hz, 1 H), 5.75 (s, 1 H), 6.26 (dd, *J* = 16, 2.2 Hz, 1 H), 6.72 (d, *J* = 16 Hz, 1 H), 8.01 (d, *J* = 16 Hz, 1 H), 11.1 (s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 14, 19.5, 22.1, 27, 29.2 (2 C), 33.7, 34.5, 40, 90, 96.6, 112.2, 116.2, 116.4, 133, 136.4, 137.6, 142.7, 157.8, 172.

MS (EI, 70 eV): *m*/*z* (%) = 298 (39) [M$^+$], 283 (97), 237 (63), 183 (31), 155 (29), 115 (47), 91 (40), 55 (38), 43 (42), 41 (100), 39 (42).

***tert*-Butyl (2*Z*,4*E*,8*E*)-3-Methyl-9-(2,6,6-trimethylcyclohex-1-enyl)nona-2,4,8-trien-6-ynoate (18e)**
Yield: 78%; yellow oil.

IR (neat): 3095, 2987, 2870, 2200, 1725, 1600, 1200 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.01 (s, 3 H), 1.41–1.45 (m, 2 H), 1.46 (s, 9 H), 1.54–1.60 (m, 2 H), 1.71 (s, 3 H), 1.94 (d, *J* = 1.3 Hz, 3 H), 2.0 (d, *J* = 6.3 Hz, 2 H), 5.60 (d, *J* = 1 Hz, 1 H), 5.61 (dd, *J* = 15, 2.4 Hz, 1 H), 6.10 (dd, *J* = 16, 2.4 Hz, 1 H), 6.67 (d, *J* = 16 Hz, 1 H), 8.1 (d, *J* = 16 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 19.5, 20.6, 22.1, 28.7 (3 C), 29.2 (2 C), 33.7, 34.5, 40, 80.5, 89, 96, 112.3, 115.4, 120.7, 132.7, 137.5, 137.8, 142.2, 148.5, 165.9.

MS (EI, 70 eV): *m*/*z* (%) = 340 (9) [M$^+$], 284 (41), 269 (83), 239 (13), 215 (27), 115 (21), 57 (100), 43 (20), 41 (90), 39 (22).

(2*Z*,4*E*,8*E*)-3-Methyl-9-(2,6,6-trimethylcyclohex-2-enyl)nona-2,4,8-trien-6-ynoic Acid (18f)
Yield: 85%; colorless oil.

IR (neat): 3100, 2983, 2870, 2190,1685, 1650, 1610, 1180 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.86 (s, 3 H), 0.9 (s, 3 H), 1.5–1.13 (m, 4 H), 1.58 (d, *J* = 1.6 Hz, 3 H), 1.98–2.01 (m, 2 H), 2.02 (d, *J* = 1 Hz, 3 H), 2.18 (d, *J* = 9 Hz, 1 H), 5.48 (br s, 1 H), 5.68 (dd, *J* = 15.8, 2.2 Hz, 1 H), 5.75 (br s, 1 H), 6.12 (dd, *J* = 15.8, 9 Hz, 1 H), 6.18 (dd, *J* = 16, 2.2 Hz, 1 H), 8.04 (d, *J* = 16 Hz, 1 H), 9.7 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 21, 23.3, 23.4, 27.3, 28, 31.7, 33, 55.5, 88, 96, 111, 116.8, 118, 122, 133, 137, 147.6, 152, 171.

MS (EI, 70 eV): *m*/*z* (%) = 284 (23) [M$^+$], 183 (74), 169 (46), 167 (75), 155 (44), 153 (45), 141 (56), 128 (69), 122 (64), 115 (73), 105 (69), 91 (100), 43 (58), 41 (95).

(2*Z*,4*E*,8*E*)-3-Methyl-9-(2,6,6-trimethylcyclohex-2-enyl)[2-^{2}H]nona-2,4,8-trien-6-ynoic Acid (18g)
Yield: 76%; colorless oil.

IR (neat): 3090, 2985, 2880, 2300, 2190, 1685, 1600, 1160 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.9 (s, 3 H), 0.95 (s, 3 H), 1.55–1.19 (m, 2 H), 1.63 (d, *J* = 1.5 Hz, 3 H), 2.04–2.08 (m, 2 H), 2.06 (s, 3 H), 2.24 (d, *J* = 9.5 Hz, 1 H), 5.5 (br s, 1 H), 5.68 (dd, *J* = 15.7, 2.2 Hz, 1 H), 6.08 (dd, *J* = 15.7, 9.5 Hz, 1 H), 6.14 (dd, *J* = 16.2, 2.2 Hz, 1 H), 8.00 (d, *J* = 16.2 Hz), 10.5 (br s, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 21, 23.3, 23.5, 27.3, 28, 31.8, 33, 55.5, 88, 95.7, 111, 116, 117 (t, J_{C-D} = 27 Hz), 122, 133, 137, 147.6, 152, 171.5.

MS (EI, 70 eV): *m*/*z* (%) = 285 (10) [M$^+$], 193 (35), 184 (23), 170 (23), 155 (27), 154 (28), 122 (35), 107 (43), 105 (41), 91 (43), 55 (44), 44 (39), 43 (75), 41 (100), 39 (51).

(2*Z*,4*E*,8*E*)-3-Methyl-9-(2,6,6-trimethylcyclohexa-1,3-dienyl)nona-2,4,8-trien-6-ynoic Acid (18h)
Yield: 72%; colorless oil.

IR (neat): 3102, 2985, 2871, 2189,1684, 1652, 1609, 1180 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.02 (s, 6 H), 1.87 (s, 3 H), 2.02 (s, 3 H), 2.05 (d, *J* = 5 Hz, 2 H), 5.71 (s, 1 H), 5.72–5.84 (m, 3 H), 6.17 (d, *J* = 15 Hz, 1 H), 6.66 (d, *J* = 16.3 Hz, 1 H), 8.03 (d, *J* = 16.3 Hz, 1 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 20.4, 20.6, 26.8 (2 C), 34, 40, 90.7, 96.6, 111.2, 116.5, 117.8, 126.6, 129.6, 129.8, 137, 137.4, 140.5, 151, 171.

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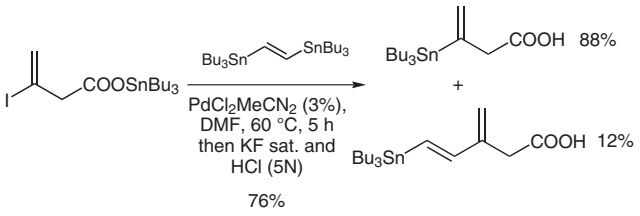

Scheme 14 Reaction of (*E*)-1,2-bis(tributylstannyl)ethene with a decongugated alkenoate

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