

Bicyclic allyltin derivatives through selective “one pot” hydrostannation-Diels Alder reaction

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Abstract: In this paper we report a simple synthetic route to obtain functionalized allyltin derivatives from 1-ethynylcyclohexene (1), through a "one pot" procedure. Radical addition of trineophyltin hydride to 1 leads quantitatively to (Z,E)-1-(2-trineophylstannylvinyl)-cyclohexene (3), a conjugated dienylstannane that, through a [4+2] cycloaddition reaction (Diels -Alder) with activated dienophiles, allows to obtain substituted bicyclic unsaturated products with specific stereochemistry and a trialkylstannyl group in allylic position.

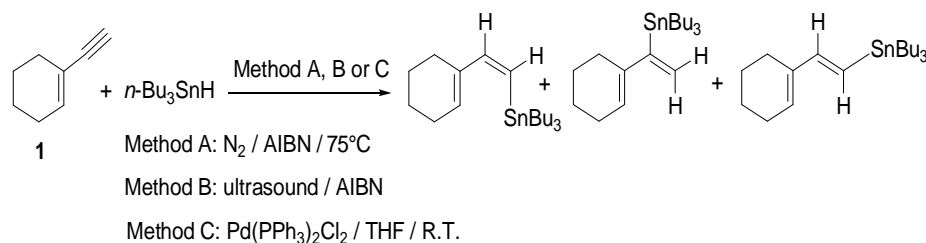
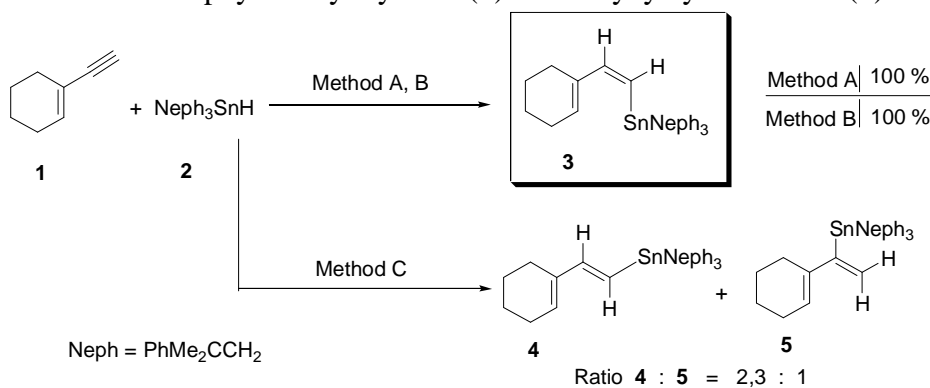
Keywords: bicyclic allyltin; hydrostannation; Diels Alder reaction.

Introduction

The Diels Alder reaction is probably one of the most used organic reactions to construct, in a regio- and stereocontrolled way, a six membered ring with up to four stereogenic centres.¹ The widespread utility of the reaction rests on its ability to form molecules otherwise difficultly accessible such as bridged bicyclic compounds and also more complex structures due to its potential to form carbon-carbon, carbon-heteroatom and heteroatom-heteroatom bonds. The synthesis of stereodefined conjugated dienylstannanes is an area of interest as they are very useful synthetic intermediates. We are interested in developing a fast route to obtain this type of precursors in order to study them as dienes in a “one pot” Diels Alder reaction. On the other hand, allyltin reagents are very important in organic and asymmetric synthesis,² as shown, for instance, in reactions of allylstannanes with aldehydes in the presence of chiral non-racemic ligands coordinated with Lewis acids.³ Taking into account the previous discussion, we now report the synthesis of a variety of functionalized compounds containing allyltin structures through a “one pot” hydrostannation-Diels Alder reaction. These compounds should be suitable building blocks of analogs of non-steroidal compounds which are selective modulators (i.e., agonists and antagonists) of a steroid receptor, specifically, the glucocorticoid receptor. Such receptors are useful to treat diseases such as obesity, diabetes, inflammation and others.⁴ Thus, the possibility of synthesizing such precursors through a “one pot” reaction is, certainly, the main target we are aiming at *via* these studies. The allyltin compounds obtained are being tested in palladium catalyzed C-C coupling reactions with the aim to obtain tin moiety free non-steroidal analogs. The results of these investigations are being analyzed and will be reported in a future communication.

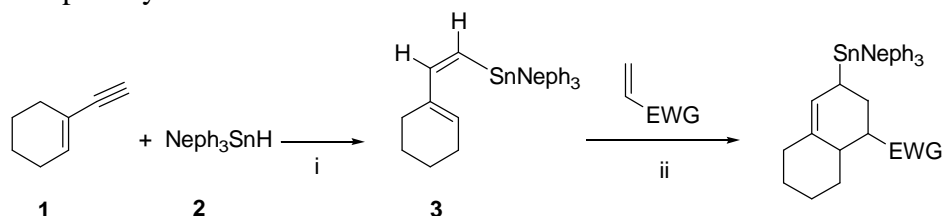
Results and Discussion

We first carried out the hydrostannation of 1-ethynylcyclohexene (**1**) with the easy to handle and commercially available tri-*n*-butyltin hydride under three different reaction conditions: Method A: free radical conditions and photochemical initiation, nitrogen atmosphere, 0.01 equivalents of azobisisobutyronitrile (AIBN), without solvent, at 75° C; Method B: free radical conditions using ultrasound,⁵ nitrogen atmosphere, r.t., 0.01 equivalents of azobisisobutyronitrile (AIBN), without solvent and Method C: under catalyzed conditions, r.t. in THF containing 2% of bis(triphenylphosphine) palladium (II) chloride (Scheme 1). The ¹¹⁹Sn NMR spectra of the crude products resulting from these additions clearly showed that a mixture of at least three dienyltin adducts was obtained. In previous studies with mono- and disubstituted alkynes,⁶ we demonstrated that it is possible to improve the selectivity of this reaction using organotin hydrides with bulky organic ligands. In view of the poor regio- and stereoselectivity found in the hydrostannation showed in Scheme 1, we considered that it could be interesting to study the addition of trineophyltin hydride (**2**) to enyne **1** under the same previous reaction conditions. As shown in Scheme 2, the results obtained were substantially different. In the case of Methods A and B under free radical conditions, (*Z*)-2-(1-cyclohexenyl)-1-ethenyl(trineophyl)stannane (**3**) resulting from an *anti* attack was the only product obtained in quantitative yield after 1 hr (Method A) and 40 min (Method B) of reaction respectively.

Scheme 1. Addition of tri-*n*-butyltin hydride to 1-ethynylcyclohexene (**1**).**Scheme 2.** Addition of trineophylstannyl hydride (**2**) to 1-ethynylcyclohexene (**1**).

The geometry of compound **3** was assigned on the basis of the large $^3J(\text{Sn}, \text{H})$ coupling constant over 151.3 Hz that indicate the existence of *trans* H-C-C-Sn linkages. The absence of the signal corresponding to a terminal vinyl methylene in the ^{13}C NMR spectra confirms that the tin atom is attached to a different vinylic carbon than the cyclohexenyl moiety. The structure was confirmed by other ^1H , ^{13}C and ^{119}Sn NMR data (see Experimental Section). When the reaction was performed using Method C under catalyzed conditions and after 45 min, a mixture of (E)-2-(1-cyclohexenyl)-1-ethenyl(trineophyl)stannane (**4**) and 1-(1-cyclohexenyl)vinyl(trineophyl)stannane (**5**) was found in a ratio of 2.3 : 1 respectively. The ratio of isomers was determined through the corresponding ^{119}Sn NMR spectrum of the crude product. These adducts are the result of the corresponding *syn* addition of the trineophyltin hydride. No addition to the double bond of enyne **1** was observed in any case. Although the mixture of regioisomers **4** and **5** could not be separated, we were able to obtain enriched mixtures which enabled us to get the NMR data of each one. The stereochemistry of **4** and **5** was assigned taking into account that the $^3J(\text{Sn}, \text{H})$ coupling constant value over 69.8 Hz extracted from the ^1H NMR spectrum lies in the range 65-85 Hz, which indicates a *cis* arrangement between the proton attached to the same vinyl carbon as the cyclohexenyl moiety and the stannyl group in stereoisomer **4**. On the other side, $^3J(\text{H}, \text{H})$ over 19.1 Hz indicates *trans* H-C-C-H linkages around the vinyl group in the same adduct. In the case of compound **5**, the $^2J(\text{Sn}, \text{C})$ coupling constant of 28.2 Hz in the signal corresponding to a CH₂ at 123.41 ppm in the ^{13}C NMR spectra together with a $^2J(\text{H}, \text{H})$ and $^3J(\text{Sn}, \text{H})$ coupling constants values of 2.3 Hz and 67.5 Hz respectively, confirms both the existence of a terminal sp² carbon and cyclohexenyl- and trineophyltin groups attached to the same vinyl carbon. Other ^1H , ^{13}C and ^{119}Sn NMR data also confirmed the assigned structures (see Experimental Section).

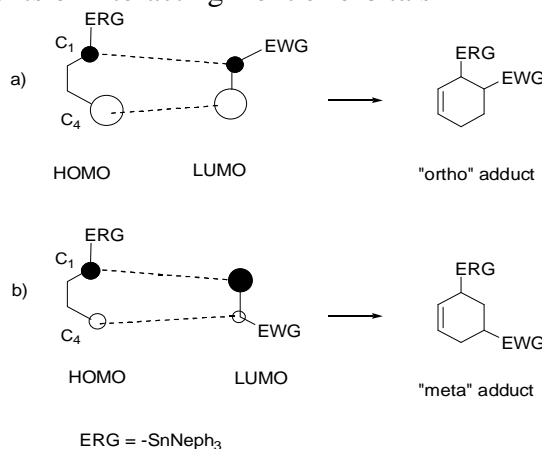
As we were looking for the best conditions for a “one pot” hydrostannation-Diels Alder reaction, we then selected the addition of Neph₃SnH (**2**) to **1** using Method B (Scheme 3).

Scheme 3. “One pot” hydrostannation-Diels Alder reactions.

Reagents: i) Method B: ultrasound / AIBN (100%); ii) Method D: methylene dichloride, aluminum trichloride, -78°C ; Method E: benzene, hydroquinone, 80°C ; Method F: benzene, hydroquinone, 40°C , ultrasound.

Since the trialkylstannyl group is known to have a small electro-donating inductive effect⁷ when is attached to a dienic sp^2 carbon atom, it would be an adequate structure to react readily with electron-poor dienophiles. The adducts obtained in these reactions should reflect the stereochemistry of the starting compounds. So, without further purification, the dienylstannane **3** was used as the conjugated diene precursor for the Diels Alder reaction performed under three different experimental conditions with several activated dienophiles: Method D: methylene dichloride, aluminum trichloride, -78°C ; Method E: benzene, hydroquinone (as polymerization inhibitor), 80°C and Method F: benzene, hydroquinone, 40°C , ultrasound. The results are shown in Table 1.

The formation of the “*ortho*, *meta* or *para*” adducts in the Diels Alder reaction in most cases can be explained in terms of Frontier Orbitals Theory and it is possible to predict the regiochemistry of these $[4n + 2]$ cycloadditions. Thus, the strongest interaction will be between the centers on the frontier orbitals having the largest orbital coefficients, which are, in this case, the HOMO of the diene with an electron-releasing group (ERG) in C_1 that reacts with the LUMO of the dienophile with an electro-withdrawing group (EWG). The most favored regioisomer that should be expected is the “*ortho*” adduct (Scheme 4, a). However, when the diene is substituted in C_1 with a weak ERG such as the trineophylstannyl group, its contribution to the distortion effect on the size of the orbital is very small so the coefficients of C_1 and C_4 will be very similar. Because of this, in the determination of the regiochemistry, the predominant effect will be the steric and then, the preferred product will be the “*meta*” adduct (Scheme 4, b). This structural hypothesis was confirmed through the spectroscopic analyses of the products obtained in the corresponding “one pot” reactions.

Scheme 4. Relative coefficients of interacting frontier orbitals

Thus, the reaction of diene **3** and methyl acrylate (**6**, entry 1, Table 1), gave exclusively methyl-4-trineophylstannyl bicyclo[4.4.0]dec-5-ene-2-carboxylate (**14**) with 92% yield under Method E conditions and 75% yield in the presence of Lewis acid at $-78\text{ }^{\circ}\text{C}$ (Method D). Only starting material was recovered when ultrasound was used (Method F). The absence of Sn, C coupling constants between the tin atom and the carbonylic group and the signals at $\delta\ 24.41$ [$^2\text{J}(\text{Sn},\text{C}) = 15.2\ \text{Hz}$] corresponding to a methylene group (C_3), clearly showed that **14** is the “*meta*” adduct together with the observed $^3\text{J}(\text{Sn}-\text{C}_4-\text{C}_3-\text{C}_2) = 11.2\ \text{Hz}$, that, according to previous work and the graphic of the Karplus equation⁸, corresponds to a dihedral angle close to 110° which shows a *trans* relation between the carboximethyl group and the tin moiety. As expected, 4-trineophylstannyl-1,3,3a,4,6,7,8,9,9a,9b-decahydrobenzo[e]isobenzofuran-1,3-dione (**15**) was the only cycloaddition product in the reaction between **3** and the symmetric maleic anhydride (**7**, entry 2, Table 1). The *trans* geometric relationship between the tin atom and the nearest carbonylic group (C_3) was determined through the $^3\text{J}(\text{Sn}-\text{C}_4-\text{C}_{3a}-\text{C}_3=\text{O})$ coupling constant value of 64.6 Hz extracted from ^{13}C NMR spectra that arises a $150\text{-}180^{\circ}$ dihedral angle between C_4-Sn bond and $\text{C}_3=\text{O}$ group. This hypothesis could be confirmed taking into account that the observed $^3\text{J}(\text{H}, \text{H})$ coupling constant value between H-3a and H-9b is about 2.3 Hz consistent with a *cis* relation among them. Once again, the highest yield of 95 % for adduct **15** occurred under the experimental conditions given by Method E. A similar analysis allowed us to determine the structure of 8-trineophylstannyl-tricyclo[8.4.0.0^{2,7}]tetradeca-4,9-diene-3,6-dione (**16**), obtained from the reaction between **3** and *p*-benzoquinone (**8**, entry 3, Table 1).

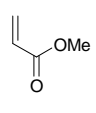
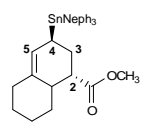
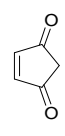
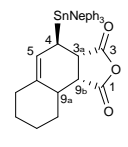
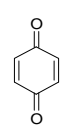
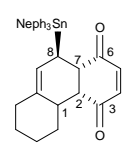
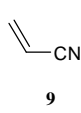
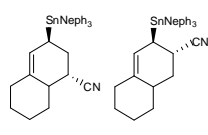
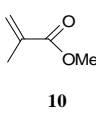
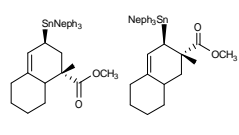

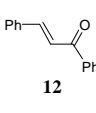
The value of $^3\text{J}(\text{Sn}, \text{C}) = 53,8\ \text{Hz}$ among the trineophyltin group attached to C_8 and the carbonyl group (C_6) indicates a dihedral angle close to 150° . Following the same analysis as before, $^3\text{J}(\text{H}, \text{H})$ coupling constant value between H_2 and H_7 of 3.0 Hz shows a *cis* type arrangement among them.

In this case, both Methods E and F gave **16** in 91 and 87% yield respectively. When the reaction was performed using acrylonitrile as the starting dienophile, (**9**, entry 4, Table 1), the formation of two adducts was observed when benzene and hydroquinone were used (Method E) in a 7.3 : 1 relation respectively according to ^{119}Sn spectra of the crude product. Only starting material was recovered under the other two reaction conditions. Column chromatography purification was very difficult because of the very similar interaction of both adducts with silica gel or alumina.

However, 4-trineophylstannylbicyclo [4.4.0]dec-5-en-2-yl cyanide (**17**) could be isolated and for **17'** characterization an enriched mixture was used. The ^1H and ^{13}C spectra analysis data shows that the “*meta*” adduct (**17**) is the predominant regioisomer and the “*ortho*” adduct, 4-trineophylstannylbicyclo[4.4.0]dec-5-en-3-yl cyanide (**17'**) is the minor one. These conclusions about each structure lies on the fact that there is a CH_2 signal at 34.13 ppm with $^2\text{J}(\text{Sn}, \text{C})$ of 10.3 Hz coupling constant value in the case of **17** and a CH signal at 39.26 ppm with $^2\text{J}(\text{Sn}, \text{C})$ of 11.2 Hz for **17'**. Besides, there is a $^3\text{J}(\text{Sn}, \text{C}, \text{C}, \text{CN})$ of 24.7 Hz that should be consistent with a dihedral angle of about 120 degrees that would indicate a *trans* relation between nitrile group and the tin moiety in compound **17'**. The absence of any coupling constant between the same groups in **17**, would justify the *meta* arrangement proposed for this adduct.

On the other side, α -substituted dienophiles gave very different results. Only 20% yield was observed in the cycloaddition reaction when 2-methyl-methylacrylate was used (**10**, entry 5, Table 1).

Table 1. Diels Alder reactions between adduct **3** and activated dienophiles **6** – **12**.

Entry	Dienophile	Method ^a / (Time, h)	Yield (%) ^b	Product
1	 6	D / (48)	75	 14
		E / (22)	92	
		F / (22)	^c	
2	 7	D / (48)	70	 15
		E / (20)	95	
		F / (12)	30	
3	 8	D / (10)	35	 16
		E / (6)	91	
		F / (11)	87	
4	 9	D / (48)	^c	 17
		E / (20)	70 ^d	
		F / (72)	^c	
5	 10	D / (48)	^c	 18
		E / (20)	20 ^d	
		F / (72)	^c	
6	 11	D / (48)	^c	-----
		E / (20)	^c	
		F / (72)	^c	
7	 12	D / (48)	^c	-----
		E / (20)	^c	
		F / (72)	^c	

^a Method D: CH₂Cl₂ / AlCl₃ / -78 °C; Method E: benzene / hydroquinone / 80 °C; Method F: benzene, hydroquinone, 40 °C, ultrasound; ^b After chromatographic purification; ^c Starting material is recovered; ^d As a mixture of two regioisomers.

Under the conditions fixed by Method E (benzene / hydroquinone), a mixture of two regioisomers, methyl 2-methyl-4-trineophylstannylbicyclo [4.4.0]dec-5-ene-2-carboxylate (**18**) and methyl 3-methyl-

4-trineophylstannylbicyclo[4.4.0]dec-5-ene-3-carboxylate (**18'**) were obtained in a 3 : 1 relation respectively according to the ^{119}Sn NMR spectrum of the crude product. No reaction was detected in other cases (Method D and F, see Table 1). Purification by column chromatography on silica-gel 60 only gave enriched fractions of each adduct and according to their spectral data (^1H and ^{13}C) we were able to analyze the possible structure of each one. The absence of the ^3J coupling constant between the trineophyltin group and the carbonyl group in **18** possibly indicates that, once again, the major product was the “*meta*” adduct. Instead, the observed ^3J (Sn, C=O) = 12.3 Hz, corresponding to a dihedral angle close to 110° should show a *trans* relation between the carboximethyl group and the tin moiety in the “*ortho*” adduct (**18'**). Comparing methylacrilate (**6**) with 2-methyl-methylacrilate (**10**), the methyl group in C_2 seems to change dramatically the yield of the reaction (entries 1 and 5, Table 1) probably due to both the steric hindrance and the weak electron-releasing capacity of this group that diminishes the electron-withdrawing effect of the carbonyl moiety. It is important to note that no cycloaddition product at all was obtained in the reactions conducted with dienophiles **11** and **12** (entry 6 and 7, Table 1). This may be explained taking into account that, in spite of the conjugating effect of the phenyl group, there should be an important steric hindrance factor that delays too much the course of the reaction.

From all these studies, we are able to show that, in the presence of suitable activated dienophiles, it is possible to carry out “one-pot hydrostannation-Diels Alder” reactions to obtain allylstannyl compounds as important precursors intermediates in very high yields that can be easily purified at the end of the synthesis by column chromatography.

Experimental Section

General

All reactions were carried out under argon or nitrogen atmosphere. ^1H , ^{13}C , COSY and ^{119}Sn NMR spectra were recorded on a Bruker ARX 300 Multinuclear instrument and calibrated by using signals from solvents referenced to SiMe_4 (^1H , ^{13}C , COSY) and with respect to Me_4Sn in the case of ^{119}Sn -NMR spectra and chemical shifts are reported in ppm. The reactions under ultrasonic conditions were performed in an ULTRASONIC 104X bath. Elemental analyses (C, H) were performed in an EXETER CE-440 instrument at UMYMFOR (Argentina). High-resolution mass spectra (HRMS) were recorded on a BRUKER micrOTOF-Q II spectrometer (HR-ESI-MS) at UMYMFOR (Argentina). Melting points were determined with a Kofler Hot-Stage apparatus and are uncorrected. All the solvents and reagents were analytical grade. Solvents were dried using standard procedures. Trineophyltin hydride was prepared as described previously.⁹

Addition of trineophyltin hydride (2) to 1-ethynylcyclohexene (1) under radical conditions. Typical Procedure. Synthesis of (Z)-2-(1-cyclohexenyl)-1-ethenyl(trineophyl)stannane (3).
Method A. 1-ethynylcyclohexene (**1**), (0.405 mL, 2.5 mmol) was treated for 60 min. with trineophyltin hydride (**2**) (1.305 g, 2.5 mmol) under nitrogen atmosphere at 75°C and with AIBN as a catalyst (this optimal time of reaction was monitored by taking samples and observing the disappearance of the Sn-H absorption by IR and products formation by ^1H NMR). The ^{119}Sn NMR

spectrum of the crude product showed that only adduct 3 was obtained in quantitative yield as a colorless oil that was used without further purification. ^1H NMR (300.000 MHz, CDCl_3) δ 7.61-7.36 (m, 15H), 6.91 (d, 1H, $^3\text{J}(\text{H}, \text{H})$ 13.5 Hz, $^3\text{J}(\text{Sn}, \text{H})$ 151.3 Hz), 5.77 (m, 1H), 5.57 (d, 1H, $^3\text{J}(\text{H}, \text{H})$ 13.4 Hz), 2.35 (m, 2H), 2.27 (m, 2H), 1.80-1.97 (m, 4H), 1.35 (s, 6H), 1.51 (s, 18H); ^{13}C NMR (75.432 MHz, CDCl_3) δ 152.09 ($^3\text{J}(\text{Sn}, \text{C})$ 24.1 Hz), 148.67, 139.85 ($^3\text{J}(\text{Sn}, \text{C})$ 28.2 Hz), 130.27 ($^1\text{J}(\text{Sn}, \text{C})$ 372.2 Hz), 128.47, 125.94, 125.83 ($^2\text{J}(\text{Sn}, \text{C})$ 7.10 Hz), 125.33, 38.72 ($^2\text{J}(\text{Sn}, \text{C})$ 18.8 Hz), 33.52 ($^3\text{J}(\text{Sn}, \text{C})$ 34.0 Hz), 33.13 ($^1\text{J}(\text{Sn}, \text{C})$ 332.2 Hz), 28.61, 25.97, 23.10, 22.69; ^{119}Sn NMR (111.817 MHz, CDCl_3): δ -89.69 ppm; HR-MS (EI): calcd for $\text{C}_{38}\text{H}_{50}\text{Sn}$ 625.5136, found 625.5139. Anal. Calcd for $\text{C}_{38}\text{H}_{50}\text{Sn}$: C, 72.90; H, 8.39. Found: C, 72.75; H, 8.30.

Method B. 1-ethynylcyclohexene (1), (0.405 mL, 2.5 mmol), was treated with trineophyltin hydride (2) (1.305 g, 2.5 mmol) and AIBN as a catalyst under argon atmosphere in an ultrasonic bath during 40 min. The reaction was monitored as mentioned above. The ^{119}Sn NMR spectrum of the crude product showed that only adduct 3 was obtained in quantitative yield as a colorless oil that was used without further purification.

Addition of trineophylstannyl hydride (2) to 1-ethynylcyclohexene (1) catalyzed by bis(triphenylphosphine)palladium(II) chloride. Synthesis of (E)-2-(1-cyclohexenyl)-1-ethenyl(trineophyl)stannane (4) and 1-(1-cyclohexenyl)vinyl(trineophyl)stannane (5).

Method C. To a solution of 1-ethynylcyclohexene (1) (0.405 mL, 2.5 mmol) and bis(triphenylphosphine)palladium(II) chloride (0.07 g; 0.05 mmol) in dry THF (7 mL) under nitrogen atmosphere was added trineophylstannyl hydride (2), (1.305 g; 2.5 mmol), and the mixture was stirred at room temperature during 45 min. Dry hexane (10 mL) was added and cooled over 10 min. at 0 °C. The resultant residue of catalyst was filtered through porous plate and the solvent was distilled off under reduced pressure. The ^{119}Sn NMR spectrum showed two signals corresponding to adducts 4 and 5 in a ratio 70 : 30 respectively. The mixture of isomers could not be separated. However, enriched mixtures of 4 and 5 obtained by column chromatography on silica gel 60 eluted with 90:10 (hexane/ethyl ether) were used for structural analysis. Compound 4: ^1H NMR (300.000 MHz, CDCl_3) δ 7.61-7.06 (m, 15H), 6.28 (d, 1H, $^3\text{J}(\text{H}, \text{H})$ 19.1 Hz, $^3\text{J}(\text{Sn}, \text{H})$ 69.8Hz), 5.70 (t, 1H, $^3\text{J}(\text{H}, \text{H})$ 7.0 Hz), 5.50 (d, 1H, $^3\text{J}(\text{H}, \text{H})$ 19.1, $^3\text{J}(\text{Sn}, \text{H})$ 76.4Hz), 2.27-2.06 (m, 4H), 2.05-1.96 (m, 4H), 1.29 (s, 18H), 1.10 (s, 2H, $^2\text{J}(\text{Sn}, \text{H})$ 12.2Hz); ^{13}C NMR (75.432 MHz, CDCl_3) δ 158.97 ($^3\text{J}(\text{Sn}, \text{C})$ 74.0Hz), 152.07 ($^3\text{J}(\text{Sn}, \text{C})$ 24.8Hz), 148.27 ($^2\text{J}(\text{Sn}, \text{C})$ 11.2Hz), 129.15, 128.41, 127.27 ($^1\text{J}(\text{Sn}, \text{C})$ 411.6Hz), 125.97, 125.79, 38.60 ($^2\text{J}(\text{Sn}, \text{C})$ 17.6Hz), 33.46 ($^3\text{J}(\text{Sn}, \text{C})$ 34.2Hz), 32.28 ($^1\text{J}(\text{Sn}, \text{C})$ 321.4Hz), 26.27, 24.29, 23.15, 22.97; ^{119}Sn NMR (111.817 MHz, CDCl_3): δ -80.37 ppm. Compound 5: ^1H NMR (300.000 MHz, CDCl_3) δ 7.61-7.06 (m, 15H), 5.76 (d, 1H, $^2\text{J}(\text{H}, \text{H})$ 2.0 Hz), 5.35 (t, 1H, $^3\text{J}(\text{H}, \text{H})$ 8.0 Hz), 5.18 (d, 1H, $^2\text{J}(\text{H}, \text{H})$ 2.3 Hz, $^3\text{J}(\text{Sn}, \text{H})$ 67.5Hz), 2.27-2.06 (m, 4H), 2.05-1.96 (m, 4H), 1.27 (s, 18H), 1.16 (s, 2H, $^2\text{J}(\text{Sn}, \text{H})$ 13.4Hz); ^{13}C NMR (75.432 MHz, CDCl_3) δ 151.94 ($^3\text{J}(\text{Sn}, \text{C})$ 22.2Hz), 141.56 ($^1\text{J}(\text{Sn}, \text{C})$ 310.4Hz), 138.18 ($^2\text{J}(\text{Sn}, \text{C})$ 34.4Hz), 128.38, 126.99 ($^3\text{J}(\text{Sn}, \text{C})$ 26.9Hz), 125.79, 125.85, 123.41 ($^2\text{J}(\text{Sn}, \text{C})$ 28.2Hz), 38.53 ($^2\text{J}(\text{Sn}, \text{C})$ 18.6Hz), 33.47 ($^3\text{J}(\text{Sn}, \text{C})$ 34.4Hz), 31.94 ($^1\text{J}(\text{Sn}, \text{C})$ 336.0Hz), 27.85 ($^3\text{J}(\text{Sn}, \text{C})$ 17.4Hz), 26.11, 23.43, 22.85; ^{119}Sn NMR (111.817 MHz, CDCl_3): δ -81.50 ppm.

“One pot” cycloaddition reaction between 3 and activated dienophiles. Typical procedure. Synthesis of 4-trineophylstannyl-1,3,3a,4,6,7,8,9,9a,9b-decahydrobenzo[e]isobenzofuran-1,3-dione (15).

Method D. In the same flask where stannyl diene 3 (1.56 g; 2.5 mmol) was obtained as mentioned above, dry dichloromethane (4.5 mL) was added and the solution was cooled to -78 °C in argon atmosphere. Aluminum trichloride (0.07 g; 0.5 mmol) and maleic anhydride (0.25 g; 2.5 mmol) were added. The resulting mixture was allowed to warm to 0 °C over a period of 60 min. and left stirring 48 hs. at room temperature. Then, was poured into 10 mL of water and extracted with three 15 mL portions of dichlorometane. The combined organic extracts were dried over anhydrous MgSO₄ and the solvent was distilled off under reduced pressure. The crude product was purified by column chromatography with silica-gel 60 and pure compound 15 eluted with 95:5 (hexane/diethyl ether) as a clear yellow oil. (1.75 mmol; 70%). ¹H NMR (300.000 MHz, CDCl₃) δ 7.36-6.93 (m, 15H), 5.00 (d, 1H, ³J(H, H) 5.4Hz, ³J(Sn, H) 17.8Hz), 2.73 (dd, 1H, ³J(H, H) 8.7Hz, ³J(H, H) 2.3Hz), 2.10 (dd, 1H, ³J(H, H) 8.6Hz, ³J(H, H) 2.3Hz), 2.08 (m, 1H), 1.92 (td, 2H, ³J(H, H) 12.4Hz, ³J(H, H) 3.6Hz), 1.78-1.55 (m, 6H), 1.68 (dd, 1H, ³J(H, H) 8.7Hz), 1.14 (s, 18H), 0.94 (s, 6H, ²J(Sn, H) 30.7Hz); ¹³C NMR (75.432 MHz, CDCl₃) δ 173.28 (³J(Sn, C) 64.6 Hz), 170.59, 149.85 (³J(Sn, C) 14.1 Hz), 131.62 (³J(Sn, C) 42.3 Hz), 127.38, 124.98, 124.22, 120.27 (²J(Sn, C) 33.5 Hz), 42.50 (³J(Sn, C) 46.6 Hz), 40.30 (²J(Sn, C) 13.6 Hz), 37.06 (²J(Sn, C) 19.4 Hz), 35.15, 32.75 (³J(Sn, C) 40.4 Hz), 32.66, 32.39 (¹J(Sn, C) 233.0 Hz), 30.63 (¹J(Sn, C) 298.1 Hz), 30.55, 26.43, 25.62; ¹¹⁹Sn NMR (111.817 MHz, CDCl₃): δ -32.15 ppm; HR-MS (EI): calcd for C₄₂H₅₂O₃Sn 723.5782, found 723.5789. Anal. Calcd for C₄₂H₅₂O₃Sn: C, 69.65; H, 7.54. Found: C, 69.74; H, 7.63.

Method E. Over a solution of 3 (1.56 g; 2.5 mmol) and 4.5 mL of dry benzene in argon atmosphere, *p*-hydroquinone (20 mg, 0.18 mmol) and maleic anhydride (0.25 g; 2.5 mmol) were added. The solution was heated 20 h at 80 °C, the solvent was vacuum removed and the product was isolated by column chromatography with neutral aluminum oxide and compound 15 eluted with 95:5 (hexane/diethyl ether), 2.38 mmol; 95%.

Method F. Over a solution of 3 ((1.56 g; 2.5 mmol) and 4.5 mL of dry benzene in argon atmosphere in an ultrasonic bath, *p*-hydroquinone (20 mg, 0.18 mmol) and maleic anhydride (0.25 g; 2.5 mmol) were added. The temperature was maintained below 40 °C during 12 hs. The solvent was distilled off under reduced pressure and product 15 was isolated as mentioned above (0.75 mmol; 30%).

Methyl-4-trineophylstannylbicyclo[4.4.0]dec-5-ene-2-carboxylate (14): ¹H NMR (300.000 MHz, CDCl₃) δ 7.25-6.98 (m, 15H), 4.97 (d, 1H, ³J(H, H) 5.6Hz, ³J(Sn, H) 49.5Hz), 3.62 (s, 3H), 2.43 (dt, 1H, ³J(H, H) 2.8Hz, ³J(H, H) 5.7Hz), 2.23 (dt, 1H, ³J(H, H) 2.8Hz, ³J(H, H) 5.7Hz), 1.93 (t, 2H, ³J(H, H) 12.4Hz), 1.87 (dd, 2H, ³J(H, H) 5.2Hz, ³J(H, H) 5.3Hz), 1.78-1.59 (m, 3H), 1.37-1.30 (m, 2H), 1.32-1.29 (m, 2H), 1.10 (s, 18H), 0.90 (s, 6H, ³J(Sn, H) 37.5Hz); ¹³C NMR (75.432 MHz, CDCl₃) δ 175.43, 150.28 (³J(Sn, C) 17.6Hz), 135.28 (³J(Sn, C) 46.7Hz), 127.07, 124.44, 124.38, 122.52 (²J(Sn, C) 37.6Hz), 51.54, 42.61 (³J(Sn, C) 11.2Hz), 38.48 (³J(Sn, C) 12.0Hz), 37.05 (²J(Sn, C) 18.2Hz), 35.43, 31.30 (³J(Sn, C) 34.6Hz), 31.02 (³J(Sn, C) 34.0Hz), 29.90, 29.61 (¹J(Sn, C) 284.7Hz), 27.84 (¹J(Sn, C) 369.2Hz), 27.31, 25.86, 24.41 (²J(Sn, C) 15.2Hz); ¹¹⁹Sn NMR (111.817 MHz, CDCl₃): δ -

46.25 ppm. HR-MS (EI): calcd for C₄₂H₅₆O₂Sn 711.6063, found 711.6059. Anal. Calcd for C₄₂H₅₆O₂Sn: C, 70.82; H, 8.26. Found: C, 70.64; H, 8.19.

8-trineophylstannyl-tricyclo[8.4.0.0^{2,7}]tetradeca-4,9-diene-3,6-dione (16): ¹H NMR (300.000 MHz, CDCl₃) δ 7.42-6.97 (m, 15H), 6.59 (d, 1H, ³J(H, H) 10.3Hz), 6.49 (d, 1H, ³J(H, H) 10.3Hz), 5.13 (d, 1H, ³J(H, H) 5.4Hz), 3.09 (dd, 1H, ³J(H, H) 6.8Hz, ³J(H, H) 3.1Hz), 2.51 (dd, 1H, ³J(H, H) 5.3Hz, ²J(Sn, H) 73.1Hz), 2.34 (dd, 1H, ³J(H, H) 6.8Hz, ³J(H, H) 3.0Hz), 2.22 (d, 1H, ³J(H, H) 5.9Hz), 1.95 (t, 2H, ³J(H, H) 10.8Hz), 1.65-1.63 (m, 4H), 1.68 (m, 2H), 1.18 (s, 18H), 0.99 (s, 6H, ³J(Sn, H) 30.0Hz); ¹³C NMR (75.432 MHz, CDCl₃) δ 202.67, 199.57 (³J(Sn, C) 53.8Hz), 151.32 (³J(Sn, C) 15.0Hz), 142.12, 140.57, 133.85 (³J(Sn, C) 44.2Hz), 121.72 (²J(Sn, C) 36.5Hz), 128.75, 126.18, 125.69, 50.98 (³J(Sn, C) 16.4Hz), 47.70, 40.12 (²J(Sn, C) 12.3Hz), 38.43 (²J(Sn, C) 18.5Hz), 37.14, 34.10 (³J(Sn, C) 36.7Hz), 31.46 (¹J(Sn, C) 293.3Hz), 29.30, 27.87, 27.24, 24.13 (¹J(Sn, C) 267.3Hz); ¹¹⁹Sn NMR (111.817 MHz, CDCl₃): δ -39.77 ppm. HR-MS (EI): calcd for C₄₄H₅₄O₂Sn 733.6083, found 733.6072. Anal. Calcd for C₄₄H₅₄O₂Sn: C, 71.97; H, 7.72. Found: C, 71.81; H, 7.53.

4-trineophylstannylbicyclo[4.4.0]dec-5-en-2-yl cyanide (17): ¹H NMR (300.000 MHz, CDCl₃) δ 7.26-6.99 (m, 15H), 5.03 (d, 1H, ³J(Sn, H) 28.6Hz, ³J(H, H) 3.5Hz), 2.64 (dt, 1H, ³J(H, H) 4.8Hz, ³J(H, H) 11.0Hz), 2.14 (dd, 2H, ³J(H, H) 16.0Hz, ³J(H, H) 14.5Hz), 1.82-1.71 (m, 4H), 1.70-1.68 (m, 2H), 1.66-1.60 (m, 2H), 1.52-1.58 (m, 2H), 0.90 (s, 6H, ²J(Sn, H) 43.1Hz), 1.10 (s, 18H); ¹³C NMR (75.432 MHz, CDCl₃) δ 150.13 (³J(Sn, C) 17.2Hz), 132.19 (³J(Sn, C) 43.2Hz), 127.18, 124.60, 124.33, 123.20 (²J(Sn, C) 33.2Hz), 119.85, 36.89 (²J(Sn, C) 18.2Hz), 36.81 (³J(Sn, C) 11.8Hz), 34.13 (²J(Sn, C) 10.3Hz), 32.52 (³J(Sn, C) 35.0Hz), 32.39 (³J(Sn, C) 35.0Hz), 31.98, 31.16 (¹J(Sn, C) 246.4Hz), 30.43, 29.48 (¹J(Sn, C) 300.8Hz), 27.54, 25.91, 24.81; ¹¹⁹Sn NMR (111.817 MHz, CDCl₃): δ -38.80 ppm. HR-MS (EI): calcd for C₄₁H₅₃NSn 679.1538, found 679.1525. Anal. Calcd for C₄₁H₅₃NSn: C, 72.44; H, 7.86. Found: C, 72.30; H, 7.73.

4-trineophylstannylbicyclo[4.4.0]dec-5-en-3-yl cyanide (17'): ¹H NMR (300.000 MHz, CDCl₃) δ 7.41-6.86 (m, 15H), 4.99 (d, 1H, ³J(Sn, H) 36.2Hz, ³J(H, H) 3.4Hz), 2.86 (dt, 1H, ³J(H, H) 6.4Hz, ³J(H, H) 12.8Hz), 2.64 (tt, 1H, ³J(H, H) 6.0Hz, ³J(H, H) 11.4Hz), 2.29-1.89 (m, 4H), 1.78-1.56 (m, 3H), 1.42-1.22 (m, 4H), 0.87 (s, 6H, ²J(Sn, H) 42.3Hz), 1.11 (s, 18H); ¹³C NMR (75.432 MHz, CDCl₃) δ 150.95 (³J(Sn, C) 16.4Hz), 134.41 (³J(Sn, C) 41.1Hz), 128.02, 125.50, 125.18, 122.8 (²J(Sn, C) 31.7Hz), 119.80 (³J(Sn, C) 24.7Hz), 39.64, 39.26 (²J(Sn, C) 11.2Hz), 36.86 (²J(Sn, C) 19.4Hz), 34.96, 34.80 (¹J(Sn, C) 239.0Hz), 34.75 (³J(Sn, C) 11.7Hz), 32.52 (³J(Sn, C) 34.6Hz), 32.43 (³J(Sn, C) 34.6Hz), 29.38 (¹J(Sn, C) 328.9Hz), 28.38, 26.70, 25.42, ¹¹⁹Sn NMR (111.817 MHz, CDCl₃): δ -37.72 ppm.

Methyl 2-methyl-4-trineophylstannylbicyclo[4.4.0]dec-5-ene-2-carboxylate (18): ¹H NMR (300.000 MHz, CDCl₃) δ 7.25-7.13 (m, 15H), 5.15 (d, 1H, ³J(H, H) 6.1Hz, ³J(Sn, H) 36.1Hz), 3.52 (s, 3H), 2.16 (t, 1H, ³J(H, H) 13.9Hz), 1.98 (t, 2H, ³J(H, H) 11.6Hz), 1.63-1.42 (m, 6H), 1.49 (s, 3H), 1.32 (d, 2H), 1.08 (s, 18H), 1.04 (m, 1H), 0.88 (s, 6H); ¹³C NMR (75.432 MHz, CDCl₃) δ 174.65, 150.50 (³J(Sn, C) 18.6Hz), 133.53, 127.07, 124.47, 124.39, 122.43 (³J(Sn, C) 34.1Hz), 51.69, 44.33 (³J(Sn, C) 16.9Hz), 41.47 (¹J(Sn, C) 245.9Hz), 41.46, 37.05 (²J(Sn, C) 10.6Hz), 36.89 (²J(Sn, C)

18.2Hz), 34.33, 33.45 ($^3J(\text{Sn}, \text{C})$ 34.6Hz), 29.23 ($^1J(\text{Sn}, \text{C})$ 292.9Hz), 26.65, 25.76, 24.92, 24.25; ^{119}Sn NMR (111.817 MHz, CDCl_3): δ -36.43 ppm.

Methyl 3-methyl-4-trineophylstannylbicyclo[4.4.0]dec-5-ene-3-carboxylate (18'): ^1H NMR (300.000 MHz, CDCl_3) δ 7.12-6.96 (m, 15H), 4.93 (d, 1H, $^3J(\text{H}, \text{H})$ 5.7Hz, $^3J(\text{Sn}, \text{H})$ 37.0Hz), 3.59 (s, 3H), 2.40 (d, 1H, $^3J(\text{H}, \text{H})$ 10.0Hz), 1.98 (t, 2H, $^3J(\text{H}, \text{H})$ 11.6Hz), 1.91-1.80 (m, 1H), 1.63-1.42 (m, 6H), 1.49 (s, 3H), 1.08 (s, 18H), 1.07 (m, 2H), 0.85 (s, 6H); ^{13}C NMR (75.432 MHz, CDCl_3) δ 178.09 ($^3J(\text{Sn}, \text{C})$ 12.3Hz), 150.41 ($^3J(\text{Sn}, \text{C})$ 18.6Hz), 133.52, 127.06, 124.45, 124.38, 121.56 ($^3J(\text{Sn}, \text{C})$ 32.9Hz), 50.91, 49.86 ($^1J(\text{Sn}, \text{C})$ 245.3Hz), 45.13, 44.33 ($^2J(\text{Sn}, \text{C})$ 9.8Hz), 38.06, 36.89 ($^2J(\text{Sn}, \text{C})$ 18.2Hz), 34.33, 33.40 ($^3J(\text{Sn}, \text{C})$ 34.0Hz), 30.10 ($^1J(\text{Sn}, \text{C})$ 292.8Hz), 27.25, 26.04, 25.55, 23.42; ^{119}Sn NMR (111.817 MHz, CDCl_3): δ -40.48 ppm.

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